Save

A. Agassiz

Cambridge Sept 1856.

THE RUDIMENTS OF CIVIL ENGINEERING, FOR THE USE OF BEGINNERS.

BY HENRY LAW,
CIVIL ENGINEER.

PART I.

New Edition,
WITH CORRECTIONS AND ADDITIONS.

LONDON:
JOHN WEALE, 59, HIGH HOLBORN.

M.DCCC.LII.

PREFACE

TO THE FIRST EDITION.

The title assumed for this little work will sufficiently explain its objects, and prevent any undue expectations on the part of the reader. It forms one of a series of works whose object is to convey a knowledge of the rudiments of the Arts and Sciences to those who were previously entirely ignorant upon such subjects.

It cannot be denied, that youth is the time to acquire knowledge with the least difficulty, the mind being then easily acted upon, and susceptible of receiving strong impressions; and the memory, not having been strained or overburdened, is then strong and vigorous. While, however, this truth has not been denied with regard to the acquisition of those branches of instruction usually given to children in schools, it has seldom been admitted when a knowledge of the Arts and Sciences has become the object of attainment, and instruction on those subjects has usually been reserved for maturer years. With what reason, however, this distinction has been made, and why the youthful mind, which easily acquires and powerfully retains the difficult and incongruous orthography of our native tongue, or the no less dry and uninteresting details of the Latin or Greek Acci-

dence, should be incapable of acquiring a knowledge calculated, above every other, to engage its attention, and excite its interest, I cannot perceive. Such an assumption is entirely gratuitous; and I believe that if a course of instruction in the Rudiments of Natural Philosophy were to be introduced into all our schools, it would be found to facilitate the advancement of the pupils in every one of their other and less interesting studies. Those who are best acquainted with children know that the mind of a child is so strong and vigorous that it may be (and in truth always is, though not always with profit) constantly employed and occupied, without injury or fatigue, but not on the same object: it is change, variety in the subject of study, that is alone necessary to render its acquisition easy and without fatigue; and such an agreeable change would be afforded by blending science with the less interesting branches of an ordinary school education.

In order to render the present work adapted to the purposes for which it is intended, the subject has been treated in as familiar and easy a manner as its peculiar nature would admit; while, however, this, its primary object, has not been lost sight of, it is hoped that the work may not be found entirely devoid of interest or information to the more advanced student.

H. L.

LONDON, June 20, 1848.

PREFACE

TO THE SECOND EDITION.

IN preparing a second edition of this little work for the press, it has been carefully examined, and such errors as were found have been corrected; besides which, several important additions have been made. In order that the work might be accessible to all, algebraical formulæ were carefully excluded in the former edition; and the whole of the rules were verbally expressed. It has, however, been thought that some formulæ, which could not be conveniently given in any other form, and which, at the same time, would be of frequent use to those conversant with algebra, might be introduced with advantage, but in order not to perplex others, they have been added in the form of notes. Amongst the most considerable additions may be mentioned the section on the Motion of bodies about Centers, and on the Moment of Inertia of bodies.

H. L.

OLD WINDSOR, 15th April, 1850.

CONTENTS OF THE FIRST PART.

CHAPTER I.

CHAPTER II.

MECHANICS.

CHAPTER III.

GENERAL CONSTRUCTION.

THE RUDIMENTS OF CIVIL ENGINEERING.

CHAPTER I.

INTRODUCTION.

THE office of the Civil Engineer consists in the designing, arrangement, and construction of all works, structures, or machines, which require the immediate superintendence of a person acquainted with the principles and practice of Construction.

Civil Engineering is one of those branches of knowledge which properly take their places both amongst the *sciences* and the *arts;* for a *science* consists of a collection of general principles or truths relating to any particular subject, while an *art* is the application of those principles to practice, for the purpose of effecting some particular object. The *Science* of Civil Engineering, then, informs us of the general principles of mechanics and construction, and teaches us in what wav to ascertain the

strains to which every part of a structure will be exposed, and of the dimensions and proportions which should be given to each, in order that they may be able to sustain such strains without injury. And the *Art* of Civil Engineering consists in the application of these principles to the actual construction of various works, and their judicious use and modification to meet the several contingencies which arise in practice.

The duty of the Civil Engineer embracing, as it does, almost every kind of construction, requires a very extensive and general acquaintance with most other sciences, in order to qualify him for successfully accomplishing the various works upon which he may be engaged, and of overcoming those difficulties which frequently start up unexpectedly in the progress of a work, and, but for the knowledge, talent, and perseverance of the Engineer, threaten the ultimate success of his endeavours. It is only necessary to take a glance at the list of Works upon the construction of which the Engineer is engaged—Railways, Roads, Canals, Rivers, Harbours, Docks, Breakwaters, Bridges, Tunnels, and many others—to obtain at once an idea of the extent of the subjects which his knowledge ought to comprise; and further, of the immense importance of his professional labours to his fellow men.

The following classified arrangement of the several branches of Civil Engineering, with their subdivisions, will not only serve to show the extent of this science,

but will guide the Engineering student in pursuing a systematic scheme in the attainment of his professional knowledge, the importance of which, both in facilitating its acquisition, and in impressing it upon the memory, are too well known, and too generally admitted, to require any enforcement.

SYNOPSIS

OF THE

SCIENCE OF CIVIL ENGINEERING.

I.—MENSURATION.

1. SURVEYING:—(1.) Description of instruments, and their use and adjustment.—(2.) Surveying in general.—(3.) Trigonometrical surveying.—(4.) Hydrographical surveying.—(5.) Mining surveying.
2. LEVELLING:—(1.) Levelling instruments, their use and adjustment.—(2.) Practice of levelling.—(3.) Measuring heights with the barometer.
3. DRAWING AND PLOTTING:—(1.) Instruments for drawing and plotting, their use.—(2.) Plotting surveys, and making plans.—(3.) Plotting levels, and making sections.—(4.) Preparing Parliamentary plans and sections.—(5.) Preparing working and contract plans and sections.—(6.) Preparing detail drawings of works, (bridges, &c.)—(7.) Making mechanical drawings.—(8.) Principles of projection, perspective, and shadows.
4. ESTIMATING:—(1.) Taking out quantities from drawings.—(2.) Measuring quantities from the works themselves.—(3.) Measuring Artificers' work.—(4.) Calculating, measuring, and valuing earthwork.—(5.) Estimating value or cost of works.
5. SETTING OUT WORKS:—(1.) Center lines and side widths of railways, roads, canals, &c.—(2.) Setting out bridges, viaducts, walls, &c.—(3.) Setting out tunnels and driftways.

II.—GENERAL CONSTRUCTION.

1. STATICS:—(1.) Composition and resolution of pressures.—(2.) Moments of pressures.—(3.) Parallel pressures, and the center of gravity.

2. Stability of Structures:—(1.) General conditions of stability.—(2.) Stability of polygonal framings.—(3.) Equilibrium of arches.—(4.) Stability of abutments and piers.—(5.) Stability of retaining walls.—(6.) Equilibrium of suspension bridges.
3. Strength of Materials:—(1.) To resist a tensile and crushing strain.—(2.) Elasticity and elongation of bodies subject to a tensile or crushing strain.—(3.) When subjected to a transverse strain.—(4.) Elasticity and deflexion of bodies subjected to a transverse strain.—(5.) To resist torsion.
4. Materials employed in Construction:—(1.) Metals.—(2.) Timber.—(3.) Natural stones.—(4.) Artificial stones, including bricks, concrete, and the various cements used in masonry.—(5.) Materials for earthwork, such as embankments, puddled banks, dams, &c.—(6.) Materials for roads and pavements.—(7.) Materials for covering roofs.
5. Different kinds of Construction:—(1.) Brickwork.—(2.) Masonry.—(3.) Forming foundations.—(4.) Carpentry.
6. Auxiliars employed in Construction:—(1.) Scaffolding, fixed and travelling.—(2.) Centerings.—(3.) Coffer Dams.

III.—MECHANICS, OR CONSTRUCTION OF MACHINERY.

1. Dynamics:—(1.) Visa viv, momentum, and work.—(2.) Motion, uniform, accelerated, or retarded; gravitation.—(3.) Collision and impact of moving bodies.—(4.) Motion down inclined planes, and curves.—(5.) Motion about fixed centers; centers of percussion, oscillation, and gyration.
2. Moving Forces:—(1.) Water as a mechanical agent.—(2.) Air as a mechanical agent.—(3.) Animal strength as a mechanical agent.—(4.) Heat as a mechanical agent; the steam engine.
3. Resistances to Motion:—(1.) Friction.—(2.) Resistance of the medium through which the body moves.
4. Theory of Machines:—(1.) Elements of machinery.—(2.) Teeth of wheels, racks, and pinions.—(3.) Transmission of work by machinery.—(4.) Determining the modulus of a machine in motion.—(5.) Mechanical expedients for transmitting or changing motion.—(6.) Proportioning the strength and dimensions of machinery.
5. Machines employed in Engineering:—(1.) Machines employed for transporting and raising materials, such as crabs, cranes, dredging machines, &c.—(2.) Machines employed in actual construction; such as pile-driving engines, excavating machines, pumps, diving-bells, pug and cement mills, &c.—(3.) Machines

for working upon materials; such as lathes, boring, planing, mortising, riveting, and screw-cutting machines, saws, &c.—(4.) Implements and tools for excavating, boring, working in wood, metals, stones, &c.

IV.—SPECIAL CONSTRUCTION.

1. Common Roads:—(1.) Principles which should control the selection of route.—(2.) Laying out roads, and arrangement of gradients.—(3.) Construction of roads.—(4.) Draining roads.—(5.) Repair of roads.—(6.) Protecting their surface by different kinds of pavement.
2. Railways:—(1.) Principles which should determine its route, and the general arrangement of the curves amd gradients.—(2.) Different systems of haulage, the locomotive, the atmospheric, and the rope.—(3.) Of the general construction of the railway.—(4.) Of the permanent way, different forms of rails, switches, &c.—(5.) Of draining the line, and maintaining the slopes and permanent way.—(6.) Arrangement of termini and stations.—(7.) Construction of engines and carriages.—(8.) System of working the line.
3. Canals:—(1.) Principles which should determine the choice of the line of a canal.—(2.) Arrangement of levels, number of locks, and form of section.—(3.) General construction of canals.—(4.) Arrangement of locks, means of saving water, and obtaining feeders.—(5.) Methods of propulsion or towing, and resistance on canals.—(6.) Construction of aqueducts.—(7.) Repair and preservation of canals.
4. Harbours and Docks:—(1.) On the construction of piers, breakwaters, and quay walls.—(2.) On the means of deepening harbours, by dredging or excavation.—(3.) Selection of site for docks, and their arrangement.—(4.) Construction and arrangement of locks; cast iron and timber gates, sluices, &c.—(5.) Construction of dock walls.
5. Bridges:—(1.) Selection of site, and determination of the kind of bridge.—(2.) Construction of stone and brick bridges.—(3.) Construction of iron and timber bridges.—(4.) Construction of suspension bridges.—(5.) Construction of railway viaducts.—(6.) Of forming the foundations of bridges.
6. Tunnels:—(1.) Determination of the form and dimensions of the tunnel.—(2.) Method of excavating and securing the ground. (3.) Sinking shafts, and driving headings or drift-ways.—(4.) Method of draining the tunnel.—(5.) Subaqueous tunnels.

V.—HYDRAULIC ENGINEERING.

1. Hydraulics :—(1.) The science of hydrostatics.—(2.) Hydrodynamics.—(3.) Pneumatics.
2. Drainage and Irrigation :—(1.) Drainage of open country, and agricultural districts.—(2.) Improvement of outfall, and diversion of water from other districts.—(3.) Surface-draining, catch-water drains, and under-draining.—(4.) Drainage of bogs and marsh lands.—(5.) Of *warping* up, and reclaiming lands from the sea and rivers.—(6.) Drainage of towns.—(7.) Form, dimensions, and declivity proper for sewers.—(8.) Of the collection and disposal of the sewage.
3. Supply of Water to Towns :—(1.) Principles which should guide the choice of the means of supply.—(2.) Different sources of supply: from the watershed of the country, from springs and Artesian wells, or from large rivers.—(3.) Means of estimating the quantity required, and of ascertaining the probable supply, and the quality of the water.—(4.) Systems of supply; the *constant*, or high pressure system, and the *intermittent*.—(5.) Selection of site for reservoirs.—(6.) Construction of reservoirs.—(7.) Contrivances for raising the water to the level of the high reservoirs.—(8.) Of the means of filtering and purifying the water, and of the construction of the filter beds.—(9.) Of the motion of water in pipes, and their discharge.
4. Marine Engineering :—(1.) Action of waves and currents, their modification by the contour of the shore, and the depth of water.—(2.) Their action on the shore, on beaches, on vertical, sloping, and curved walls, and generally on any obstacle.—(3.) On the *régime* of coasts, and their preservation.—(4.) Construction of sea-walls, embankments, breakwaters, piers, and other structures exposed to the action of the sea, more particularly as regards their form.—(5.) Principles which should determine the selection of the site for a harbour, and the arrangement of its form.—(6.) On the causes which produce shoals and bars.—(7.) Means of keeping harbours free from such obstructions, or of removing them where already existing.—(8.) On the improvement of harbours and sea channels.
5. Improvement of Rivers :—(1.) On the tidal wave at the mouth of rivers, and its modification in passing up the river.—(2.) Principle of the conservation of tidal force.—(3.) On the antagonist agencies of the tide and land waters in rivers; and the means of determining which of these should be assisted; of the *régime* of rivers.—(4.) On the form of the shore-line of rivers, and their

improvement.—(5.) Of the junction of rivers.—(6.) On the velocity of the stream, its scouring and transporting power, compared with the nature of its bed.—(7.) Effects of projections, irregularities, and obstructions, such as dams and weirs.—(8.) Of the formation and removal of shoals; their causes; of artificial scouring and sluicing.—(9.) Of the shoals formed at the mouths of rivers, their cause and prevention.

VI.—SCIENCES COLLATERALLY CONNECTED WITH ENGINEERING.

1. Somatology, or the Properties of Matter. 2. Chemical Philosophy. 3. Geology and Mineralogy. 4. Natural History. 5. Physical Geography, and Hydrography. 6. Mathematics. 7. Acoustics.	Of all these Sciences, a certain amount of knowledge is required by the Civil Engineer; but of some more than of others, depending, in a great measure, upon those particular branches of the profession to which he may more exclusively direct his attention.

The foregoing tabular view only comprises those branches which may be said to form actually a portion of the science of Civil Engineering, but is far from including every subject with which the Engineer should be conversant.

The limits, and, in fact, the object, of the present work are incompatible with a strict adherence to the above classified arrangement of the subject; and it will therefore be seen, that we have omitted altogether mention of some of the matters included in the foregoing table, and that in other cases we have deviated from and modified the method of treating the subject.

CHAPTER II.

MECHANICS.—STATICS.

One of the most important sciences to the Civil Engineer is that of Mechanics, whose object it is to make him acquainted with the laws and relations which subsist between the various strains and pressures existing in any complex structure, and so to guide him in the arrangement and distribution of its parts, and in neutralizing and adjusting those strains, as to prevent their doing any injury to the structure, and to insure its permanent stability; and further, it teaches him the effects which force produces in moving matter, and makes him acquainted with the laws by which such motions are produced, transmitted, destroyed, or otherwise modified to suit the several purposes to which he may require to apply them. The first division of Mechanics, that relating to the stability of structures, is termed *Statics;* the second, that which relates to the laws of moving bodies, is termed *Dynamics.* It will not be necessary for us to enter at length into the whole subject of Mechanics; we shall simply confine ourselves to a general exposition of those parts which are of more immediate importance to the Engineer.

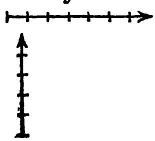
All bodies are of themselves perfectly incapable of altering their state, whether of rest or motion, and it is only by the action of some external cause

that the motion of a body, however small, can be produced, altered, or destroyed; this quality of matter is called its *inertia*, and the external cause which thus acts upon the body, creating or modifying its motion, is called a *force*. A body does not, however, always move when force is applied to it, because, at the same time, it may be acted upon by another force, whose tendency is to make it move in an opposite direction to that of the force last applied; and if these two forces be exactly balanced, or equal, no motion whatever will take place in the body. When a force thus applied to a body, is so exactly balanced by other forces, that the body does not move in consequence, then such forces are called *pressures*, and they are said to be in *equilibrium*.

Composition and Resolution of Pressures.

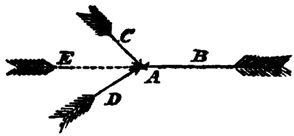
It is customary, and very convenient, to represent pressures by lines drawn on paper, the general direction of the line being the same as that of the force, and the length of the line being proportional to the amount which it represents. For example, suppose a line one-tenth of an inch in length to represent a pressure of one pound, then the annexed diagram would represent two pressures, whose directions were at right angles to each other, and equal to five and seven pounds respectively, the arrows, at the same time, serving to show the directions in which the pressures act.

Fig. 1.



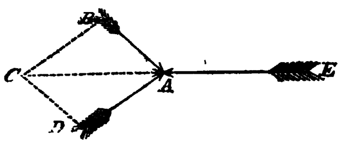
Let A in fig. 2, be a body acted on by three pressures, whose directions and amounts are represented by the three arrows B, C, and D, and are so related and adjusted, that by their joint action, the body A is in equilibrium, that is, has no tendency to move in any direction. Now let us suppose two of the forces, C and D, to be suddenly removed, and a new force E, shown by the dotted arrow, substituted for them, in a direction directly opposite to the pressure B, and in amount exactly equal to it. We have already stated, that when a body is acted upon by equal forces whose directions are exactly opposite, it is in a state of equilibrium, and therefore it is evident that in the substitution which we are just supposed to have made, we have not in any way affected the body A, and that the force E produces the same effect as did the two pressures C and D, whose places it has taken. Any pressure which will thus take the place of two or more pressures, producing precisely the same results, is said to be the *resultant* of those pressures, and the process by which the direction and amount of the resultant of any pressures is found, is termed the *composition of forces;* while the reverse process, by which we find two or more pressures, which would produce the same effect as any one given pressure, is called the *resolution of forces.*

Fig. 2.



*The resultant of any two pressures is represented, both in direction and amount, by the diagonal of a parallelogram, whose two adjacent sides represent, in direction and amount, those two pressures**. Thus, let B A and D A, fig. 3, be two pressures acting upon the body A; draw C B parallel and equal to D A, and C D parallel and equal to B A, so as to complete the parallelogram A B C D, to which draw the diagonal C A; then will C A represent, both in direction and amount, the resultant of the two pressures B A and D A. Let E A represent the pressure which is required to keep the body A in equilibrium, and prevent its being moved by the pressures B A and D A; then it is evident that E A must be equal and opposite to C A; and the three pressures B A, D A, and E A, by which the body A is kept in equilibrium, are parallel in direction, and proportional in amount, to the three sides,

Fig. 3.



* To those conversant with Algebra, the following formulæ, expressing the magnitude and direction of the resultant of any two pressures, will be useful. Let P_1 and P_2 represent two pressures, P_2 being the greater; let β be the angle formed by their two lines of direction, R their resultant, and γ the angle which its line of direction makes with that of P_2; then—

$$R = \sqrt{P_1^2 + P_2^2 \mp P_1 P_2 \cdot \cos\beta},$$

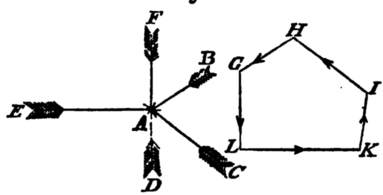
$$\tan\gamma = \frac{P_1 \cdot \sin\beta}{P_2 \mp P_1 \cdot \cos\beta};$$

In which the upper sign is to be taken when β is less than 90°, and the lower when it is greater.

B A, C B, and A C, of the triangle A B C. Or generally *any three pressures which, when applied to a body, keep it in equilibrium, are all in the same plane, and are parallel and proportional to the three sides of a triangle.*

When a body in equilibrium is acted upon by more than three pressures, whose directions are all in the same plane, then are those pressures parallel in direction, and proportional in amount, to the sides of a polygon. Thus, let the body A, fig. 4, acted

Fig 4.

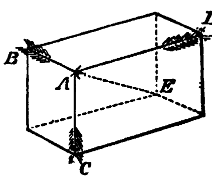


upon by the five forces B A, C A, D A, E A, and F A, be in equilibrium; then draw G H parallel and equal to A B, through H draw H I parallel and equal to A C, through I draw I K parallel and equal to A D, through K draw K L parallel and equal to A E; lastly, through L draw a line parallel and equal to A F, the end of which will be found to coincide with the point G, thus completing the five-sided polygon G H I K L G, whose sides are, by the construction, parallel and proportional to the five pressures acting on the body A.

When any three pressures act upon a body in directions which do not lie in the same plane, then is the resultant of those pressures represented, both

in magnitude and direction, by the diagonal of a parallelopipedon, whose three contiguous edges represent, both in direction and amount, the three given pressures. Thus, let B A, C A, and D A, fig. 5, be the three given pressures, all acting at the point A; construct the paral lelopipedon shown in the figure; then will the diagonal E A represent, both in direction and amount, the resultant of those three pressures.

Fig. 5.

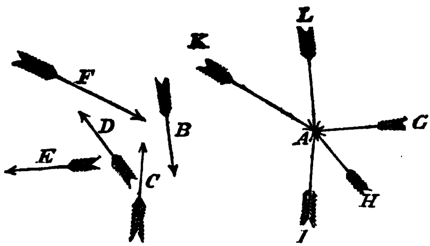


The resultant of any number of pressures, acting in any directions, may be found by the following method:—First proceed to find the resultant of any two of the pressures, considered without reference to the others; then find the resultant of this resultant and another of the pressures; then of this second resultant and some other of the pressures; and thus proceed until the number of the pressures left is only two, when the resultant of those two, being found by one of the methods just explained, will be the resultant of the whole.

If any number of pressures whose directions are all in the same plane, are in equilibrium, and if they be supposed to be moved, keeping the new direction of each pressure parallel to its former direction, so as to make them all act upon the same point, those pressures will still remain in equilibrium, whatever may be the position of that point. Thus, let

B, C, D, E, F, fig. 6, be a system of pressures all acting

Fig. 6.



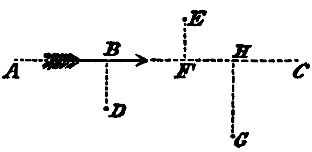
in the same plane, and in equilibrium; now, let us suppose the pressure B to be applied to the point A, in the direction L A, parallel to its former position, the pressure C to be applied in the direction I A, D in the direction H A, E in the direction G A, and F in the direction K A, all parallel to their former directions; then will the point A thus acted upon by these five pressures be in a state of equilibrium, that is, will have no tendency to move in any direction.

Moments of Pressures.

When the effect of a pressure whose direction is in any given plane, is considered with reference to some point in that plane, not situated in the direction of that pressure, such effect depends not only on the amount of the pressure, but also on the perpendicular distance of the point from the direction of the pressure; and the product of the pressure, multiplied by the perpendicular distance of its direction from the point, is termed the *moment* of

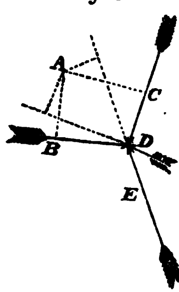
the pressure about that point. For example, if B, fig. 7, represent a pressure of nine pounds acting in the direction A C, and it be desired to measure its moments about the several points D, E, and G, if B D the perpendicular distance of the line A C from the point D equal 5, E F the distance of A C from the point E equal 4, and G H the distance of the point G from the line A C equal 8, then $9 \times 5 = 45$ will be the moment of B about the point D, $9 \times 4 = 36$, its moment about the point E, and $9 \times 8 = 72$, its moment about the point G.

Fig. 7.



If any number of pressures in equilibrium, and whose directions are all in the same plane, have their moments taken about any given point in that plane, wherever situated, then the moments which tend to turn the plane in one direction about that point, are equal to those which tend to turn it in the opposite direction. For example, let the four pressures B, C, D, E, fig. 8, be in equilibrium, and let their moments be taken about the point A; now the pressures C and D both tend to turn the plane about the point A in a direction from right to left, while the two pressures B and E tend to turn it about the same point from left to right, and it will be found that the sum of the moments of C and D

Fig. 8.



about the point A will be equal to the sum of the moments of B and E about the same point, and therefore that the two tendencies to turn the plane about A in two opposite directions are exactly equal and balanced.

If any number of pressures in equilibrium, and whose directions all lie in the same plane, are each resolved into two other pressures, acting in directions parallel to any two given lines at right angles to each other, and both situated in the same plane, then will the pressures which tend to move the plane in one direction along either of those lines, be equal to those which tend to move it in the opposite direction *. Thus, let A B, C D, E F, G H, fig. 9, be four given pressures, in equilibrium and let O N and O P be the two given lines at right angles to each other, and in

* From this theorem we deduce very simple formulæ for determining the magnitude and direction of the resultant of any number of pressures in the same plane. Let the three pressures A B, D C, and E F, (fig. 9,) be represented by P_1, P_2, and P_3, and their angles of inclination (A B I, C D K, and E F L,) with the line O P (given in position) by β_1, β_2, and β_3; then it is evident that the lines I B, D K, and L F represent the *cosines* of those angles multiplied by the pressures P_1, P_2, and P_3, and the lines A I, C K, and L E the *sines* of those angles multiplied by the same pressures. Therefore, if we put R for the resultant, and γ for its inclination to O P, we have—

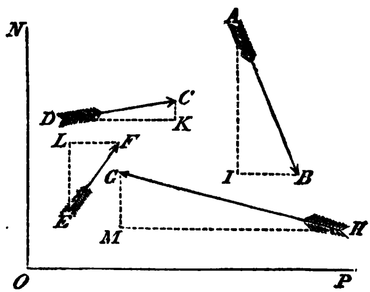
$$R \,.\, \cos\gamma = P_1 \,.\, \cos\beta_1 + P_2 \,.\, \cos\beta_2 + P_3 \,.\, \cos\beta_3$$
$$R \,.\, \sin\gamma = P_1 \,.\, \sin\beta_1 + P_2 \,.\, \sin\beta_2 + P_3 \,.\, \sin\beta_3.$$

From these we obtain,

$$R = \sqrt{\{(P_1 \,.\, \cos\beta_1 + P_2 \,.\, \cos\beta_2 \,.\,.\,.\,.\, + P_n \,.\, \cos\beta_n)^2 + (P_1 \,.\, \sin\beta_1 + P_2 \,.\, \sin\beta_2 \,.\,.\,.\,.\, + P_n \,.\, \sin\beta_n)^2\}}$$
$$\tan\gamma = \frac{P_1 \,.\, \sin\beta_1 + P_2 \,.\, \sin\beta_2 \,.\,.\,.\,.\, + P_n \,.\, \sin\beta_n}{P_1 \,.\, \cos\beta_1 + P_2 \,.\, \cos\beta_2 \,.\,.\,.\,.\, + P_n \,.\, \cos\beta_n};$$

where we are to take the terms positive or negative, according to the directions of the pressures.

Fig. 9.



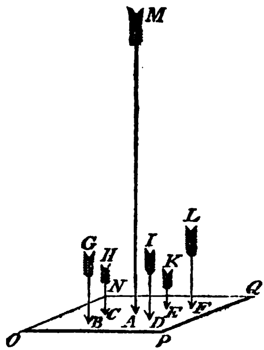
the same plane with the given pressures; now, let A B be resolved into two pressures, A I and I B parallel to N O and O P, which is done by drawing two lines through the points A and B parallel to the lines N O and O P and intersecting in I; in like manner, resolve C D into D K and K C, E F into E L and L F, and H G into H M and M G. Then the pressures which tend to move the plane upwards along the line O N are K C, E L, and M G, and that which tends to move it in the opposite direction is A I, which will be found to be equal to the sum of the other three; again, the pressures which tend to move the plane to the right along the line O P are I B, D K, and L F, and the pressure tending to move it in the opposite direction is H M, which is also equal to the sum of the other three.

Of Parallel Pressures.

If the directions of any number of pressures are parallel to each other, then the direction of their resultant is parallel to them, and, if they all act in the same direction, is equal in amount to the sum of all the pressures; but if some act in one direction, and some in another, then is their resultant equal to

the difference of the sums of those pressures which act in each direction. Any number of parallel pressures are said to be in equilibrium about a given point when, being applied on one side of a plane passing through that point, the plane would be sustained immoveably by a sufficient pressure applied to that point in a direction parallel and opposite to the given pressures, and would have no tendency to move or alter its direction. And the single pressure so applied to sustain the given pressures would be equal and opposite to the resultant of those pressures; and, therefore, a system of parallel pressures can only be in equilibrium about a point, when such point is situated in the direction of their resultant. Thus, suppose G B, H C, I D, K E, and L F, fig. 10, to be five parallel pressures, all acting in the same direction, and applied to the plane N O P Q; and let them be in equilibrium about the point A; that is, let A be that point which, if sustained by a sufficient support on the under side of the plane, would prevent its being moved by the application of the pressures: then a single pressure M A, equal in amount to the sum of all the five pressures, applied to the point A in a direction parallel to the others, will be the resultant of those pressures.

Fig. 10.



Center of Gravity.

The principle of parallel pressures is of frequent application in determining the position of the center of gravity of any complex system of bodies. For the weights of the several bodies are considered as so many pressures acting through the centers of gravity of each respectively, in directions which, though they actually tend towards the earth's center, may practically be considered as parallel; and the center of gravity of the system will be situated in the resultant of these several pressures. *The moment of the resultant of any number of parallel pressures measured from any given plane parallel to their directions, is equal to the sum of the moments of all those pressures measured from the same plane* *. In order then to determine the position of the center of gravity of any system of bodies, if we measure the moments of those bodies from three different planes taken at right angles to each other, the point of intersection of the three resultants so obtained will be the center of gravity of the system. As an example, let A, B, C, and D, fig. 11, be four bodies whose

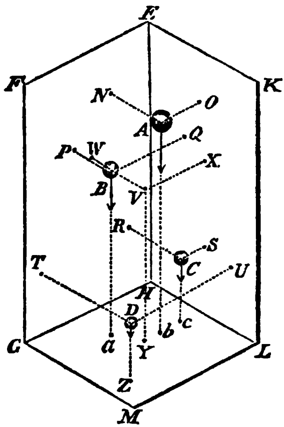
* If P_1, P_2, P_3, &c., be any parallel pressures, and d_1, d_2, d_3, &c., their perpendicular distances from any given parallel plane; also R their resultant, and D its perpendicular distance from the same plane, this and the foregoing theorem are expressed algebraically as follows:—

$$R = P_1 + P_2 \dots + P_n$$

$$D = \frac{P_1 d_1 + P_2 d_2 \dots + P_n d_n}{P_1 + P_2 \dots + P_n}.$$

common center of gravity it is desired to find. Let us assume three planes, E F G H, E K L H, and G H L M, at right angles to each other, and suppose the weights of the several bodies, their distances from each of the three planes, and the product of the two or their moments to be as stated in the following table:—

Fig. 11.



	Weight in pounds.	Distance from the plane E F G H.	Moments.	Distance from the plane E K L H.	Moments.	Distance from the plane G H L M.	Moments.
A	8	N A = 13	104	O A = 9	72	b A = 44	352
B	6	P B = 8	48	Q B = 18	108	a B = 35	210
C	4	R C = 13	52	S C = 5	20	c C = 13	52
D	2	T D = 21	42	U D = 25	50	Z D = 12	24
	20		246		250		638

Now from this table we perceive, that the sum of the moments of all the bodies, measured from the plane E F G H, is 246; from the plane E K L H, is 250; and from the plane G H L M, is 638; then, since the moment of the resultant of these pressures, measured from each of these planes, is the same as these sums,

and since the amount of the resultant is equal to the sum of the weights, or 20, it follows that, if we divide the above sums by 20, we shall obtain the distance of the resultant, or of the common center of gravity, from each of the three planes. Thus $\frac{246}{20}=12\cdot3$ is the distance W V of the centre of gravity of the whole of the four bodies A, B, C, and D, from the plane E F G H; $\frac{250}{20}=12\cdot5$ is its distance V X from the plane E K L H; and $\frac{638}{20}=31\cdot9$ is its distance V Y from the plane G H L M; and thus its position is accurately determined.

DYNAMICS.

Laws of Uniform and Variable Motion.

In the foregoing section we have considered only the action of *pressures upon bodies at rest*, and have shown how to determine the resultant of any number of pressures acting in any given directions, that is, how to determine the direction in which another pressure must be applied, and its magnitude, in order that it may produce the same effect as those pressures for which it has been substituted. We have now to examine the action of *forces in producing or maintaining motion in bodies.* The whole of the foregoing propositions, which we have given as appertaining to pressures, are equally accurate as applied to moving forces, and merely require the substitution of the word "force" for "pressure." Thus, that given at page 11, would be, as applied to Dynamics, "*The resultant of any two moving*

forces is represented, both in direction and amount, by the diagonal of a parallelogram whose two adjacent sides represent, in direction and amount, those two pressures." That is (referring to fig. 3, on the same page), if a force be applied to a body at A, in the direction A B, such as would cause it to move over the space represented by A B in a given time, and another force be at the same instant applied to A in the direction A D, and such as would cause it in the same given time to move over A D, then the space which the body A will actually describe in that time, under the simultaneous and joint influence of these two forces, will be represented both in direction and magnitude by the diagonal A C of the parallelogram constructed on A B and A D; and any single force, as A E, applied in a direction opposite to A C, and equal to it, would have produced the same result or amount of motion in the body A, and therefore C A is the *resultant* of those forces.

We have already stated that a body at rest would always remain so, unless acted upon by some external force, and that this property of matter is termed its inertia. If, however, a body be perfectly free to move, that is, have no forces whatever resisting or opposed to its motion, save only its own inertia, then will the application of any force, however small, cause the body to move, whatever may be its size: thus, were a polished globe to be placed on a perfectly smooth and level plane, and the resistance of the atmosphere and of friction entirely

removed, then would the application of the smallest conceivable force impart *some* motion to the globe, whatever might be its size, which motion would continue undiminished after the removal of the force, the globe continuing to move forward in the same direction and with the same velocity for ever. The velocity of a moving body is measured by the space which it passes over in a given time, usually assumed to be one second; and the velocity which any force would impart to a body, or the space which it would cause it to move over in a given time, would be inversely proportional to the magnitude of the body; that is, if the same force were applied to two bodies, both free to move, one double the weight of the other, the lighter body would be made to move with double the velocity of the other. In order to make this, which is one of the fundamental propositions in dynamics, perfectly well understood, we shall illustrate it by one or two familiar examples. Suppose two boats, one very much larger than the other, drawn towards each other by a rope, fixed to one and gradually wound up in the other, and suppose that the resistance offered by the air and water to the free motion of the vessel was entirely removed, then would they approach each other with velocities inversely proportional to their weights; that is, the space which the lesser boat would move over in any given time would be as much greater than that moved over by the other, as the weight of the latter exceeded that of the former. Or suppose two bodies con-

nected together by an inflexible bar, itself devoid of all weight, and let one body be four times the weight of the other, then let some external force cause these two bodies to revolve round each other, and it will be found that the circle described by the lesser body will be four times as great as that described by the larger one.

The inertia of a body, or the force required to impart a given velocity to it, does not depend upon its mere bulk, but upon the actual quantity of matter in it, which depends upon its density and mass conjointly, and is accurately represented and measured by its weight, or the force with which it gravitates to the earth.

If a force act upon a body only for a very short period, and then cease, the velocity imparted to the body will remain constant, and it will continue to move onward with the same speed for any length of time; a body under such circumstances is said to move *uniformly*, or to have a *uniform velocity*, and the measure of such velocity is usually the space which it passes over in a second of time. If, however, the force be supposed to continue its action upon the body after its first impulse, then will the body continually receive accession to its velocity, and move over a larger space each successive second. If the force remain constant in its amount, then will the additional space moved over by the body in each successive second be equal: for example, if in the first second it moved over a space of one foot, and

in the second second over a space of three feet, then, if the force remain uniform, in the third second it will move over a space of five feet, and in the fourth of seven feet, every successive second moving over a space two feet larger than that which it described during the previous second. A body thus acted upon by a constant force, and moving according to the above law, is said to move with a *uniformly accelerated* velocity. If, however, the force does not remain constant, but varies in its action, and causes the velocity of the moving body to increase according to any other law, then the body is said to move with a *variably accelerated* velocity.

In like manner if a body, having had a certain velocity imparted to it by a force which has ceased to act, be subjected to a *constant* force opposing its motion, then will its velocity be gradually diminished; and in losing its velocity it will follow the same law which it observed in acquiring it, that is, the difference between the space described in each two successive seconds of time will be always the same. A body so moving is said to have its velocity *uniformly retarded*. If, however, the opposing force is not constant, but varies in its action, then will the decrease of the body's velocity follow some other law, and it will be said to move with a *variably retarded* velocity.

The velocity of a body whose motion is variable is expressed at any given moment by the space which it would have described in a second, if its

velocity had continued for that time the same as at the given moment.

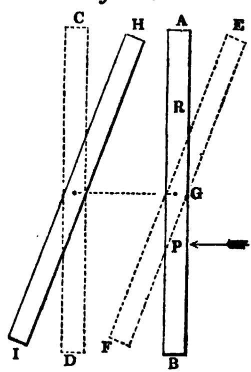
Motion of Bodies about Centers.

When a body moves through space without revolving, so that every part of it moves with the same velocity and in the same direction, as in the case of a body sliding along a plane surface, it is then said to have a *motion of translation*. If, however, any point in the body is stationary while the remainder of the body is in motion, it must revolve about that point, and is then said to have a *rotatory motion;* and the length of the arc described by any point in the body in any given time, as a second, is called its *angular velocity*. The motion of a body may be partly an angular motion and partly one of translation, an instance of which is afforded by the motion of a bullet discharged from a rifle, which, in addition to the direct progressive motion imparted to it by the impulse of the powder, has a rotatory motion given to it by spiral grooves formed for that purpose on the interior of the barrel. And we have a further instance in the paddle-wheels of a steam-boat, which are carried forward with the boat while they simultaneously revolve on their axis.

When a body previously at rest has motion imparted to it by an impulsive force, if the direction in which the force acts pass through its center of gravity, the motion is that of translation only, the body having no tendency to revolve in either direc-

tion. If, however, the direction of the force pass on one side of the center of gravity, the motion will be partly one of rotation and partly of translation, and will be subject to this remarkable law,—*that the motion of rotation will be such as would have been produced had the body been fixed on an axis passing through its center of gravity so that there could have been no motion of translation, and the motion of translation such as would have been produced had the force been applied in a direction passing through its center of gravity so that there could have been no rotation.*

Fig. 11[a].



For instance, let the rectangular body A B, fig. 11[a], be struck in the point P by an impulsive force, such as would, if it had been applied at the center of gravity G, have caused the body to move with a motion of translation into the position C D in a given time, or if applied at P and the body constrained to move on a fixed axis passing through its center of gravity G, would have caused it in the same time to assume the angular position E F; then will the body A B really assume the position H I parallel to E F, its center of gravity having moved over the same space as it would have done upon the first supposition, while the body itself

has moved about its center of gravity through the same angle as it would have done upon the second supposition. Now, wherever the point P in which the body is struck may be situated, its center of gravity will move forward with the same velocity; but its angular velocity will depend upon the distance of the point P from the center of gravity, about which center it will always, and under all circumstances, rotate. If, therefore, the force act upon the body at a point near one end B, the *angular* velocity of the extreme points, both at A and B, will be greater than the velocity of the center of gravity; and, as the end A is moving in a direction contrary to that of the center of gravity, it will actually at first move *towards* the side struck, with a velocity equal to the difference of its angular velocity and the velocity of its center of gravity. As, however, the angular velocity is less as we approach G, there will be a certain point (as R) between A and G, where it is exactly equal to the velocity of the center of gravity, which point therefore will remain stationary when the body first begins to move, the parts between R and A moving towards the force, while those between R and B move away from it. This point R is called the *center of spontaneous rotation*, and may be defined to be that point which is the last to move when a body is struck, or about which it instantly commences to rotate; and the point P in which the body is struck is called the *center of percussion*. The distance of the point R from the center of gravity

depends upon the distance of the point P from the same, the former *increasing* as the latter *decreases*: when the point P is at the end of the body B, the distance R G is one-sixth of the length A B; as the point P moves towards G, the point R moves from it, until, when the distance G P is one-sixth of the length A B, the point R coincides with the end A; and if the point P approaches still nearer to G, the center of spontaneous rotation is then situated somewhere beyond the end A of the body, the distance between it and the center of gravity increasing rapidly as P approaches G, until, when they coincide, the distance becomes infinite, or, as before stated, the body has no rotation.

The centers of spontaneous rotation and of percussion are reciprocal; that is, if R is the center of spontaneous rotation when the body is struck in the point P, that same point would become the center of spontaneous rotation if the body were struck in the point R.

If the body were to be suspended at either of the points R or P, so as to vibrate as a pendulum, it would perform its oscillations in the same time as if the whole of the matter of the body were collected in the other point P or R; that is, if the center of spontaneous rotation of any body be taken for the center of suspension, the corresponding center of percussion will be the *center of oscillation* of that body.

The center of percussion is that point in a revolv-

ing body in which any other body should be struck in order to produce upon it the greatest effect, the whole of the moving force of the revolving body being then imparted to the opposing one.

In a body revolving about a fixed axis the moving force of any particle is proportional to its distance from that axis, and is equal to the weight of the particle multiplied by the square of that distance. Therefore the whole moving force of the body is equal to the sum of the products of all its particles multiplied by the squares of their distances from the axis of motion, and this sum is termed the *moment of inertia* of the body about that axis. If the moment of inertia be divided by the whole weight of the body, the quotient is the distance from the axis at which, if the whole of the matter of the body were collected, it would have the same moving force as before, which distance is called the *radius of gyration* for that axis.

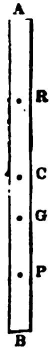
The following table contains the moment of inertia of several bodies, and also the radius of gyration of each.

Description of body.	Moment of inertia.	Radius of gyration $=\sqrt{\frac{\text{moment of inertia}}{\text{mass of body}}}$.
A slender rod, revolving about one end; $l=$ the length, and $a=$ the area.	$a\frac{l^3}{3}$	$\cdot57735\,l$
A rectangular parallelopiped, revolving about an axis passing through its center of gravity parallel to one of its edges, which edge $=h$, the other two edges $=b$ and d.	$\frac{hbd(b^2+d^2)}{12}$	$\cdot28867\sqrt{(b^2+d^2)}$
A cylinder revolving upon its axis; $h=$ the height, and $r=$ the radius.	$1\cdot5708\,hr^4$	$\cdot70711\,r$
A cylinder revolving upon an axis passing through its center of gravity, perpendicular to its own axis.	$\cdot7854\,hr^2(r^2+\frac{1}{3}h^2)$	$\frac{\sqrt{(r^2+\frac{1}{3}h^2)}}{2}$
A hollow cylinder, revolving about its axis; $h=$ the height, $r=$ the mean radius, and $t=$ the thickness.	$6\cdot283hrt\left(r^2+\frac{c^2}{4}\right)$	$\sqrt{r^2+\frac{c^2}{4}}$
A cone, revolving upon its axis; $h=$ the height, and $r=$ the radius of the base.	$\cdot31416\,hr^4$	$\cdot5477r$
A sphere, revolving about any diameter; $r=$ radius.	$1\cdot6755r^5$	$\cdot63246\,r$

If the moment of inertia of any body about an axis passing through its center of gravity be known, its moment of inertia about any other axis, parallel to the former, will be equal to the weight of the body multiplied by the perpendicular distance between the

two axes, added to the moment of inertia about the axis passing through its center of gravity.

Fig. 11[b].



In the annexed figure (11[b]) let R represent the center of spontaneous rotation, C the center of gravity, G the center of gyration, and P the center of percussion, of the rectangular body A B; then R C is to R G as R G is to R P, *or the distance of the center of gyration from the center of spontaneous rotation is a mean proportional between the distances of the center of gravity, and the center of percussion from the center of spontaneous rotation.*

In the following table we have given the values of R C, R G, and R P in a rectangular rod, as A B, when the point of spontaneous rotation is taken successively at every tenth of the half length A C; the length of the bar being taken equal to 20. In this table it will be observed that the distance between the center of spontaneous rotation and the center of percussion decreases as the former approaches the center of gravity, until it reaches a certain point, after passing which, it again increases, until upon R and C coinciding, it becomes infinite; when this takes place, the center of gyration is then called the *principal center of gyration.*

Distance of the center of spontaneous rotation from the end A of the bar.	Distance between the center of spontaneous rotation and the center of gravity.	Distance between the center of spontaneous rotation and the center of gyration.	Distance between the center of spontaneous rotation and the center of percussion.
0	10	11·546	13·333
1	9	10·693	12·704
2	8	9·856	12·167
3	7	9·074	11·762
4	6	8·327	11·555
5	5	7·638	11·667
6	4	7·024	12·444
7	3	6·506	14·111
8	2	6·110	18·667
9	1	5·859	34·333
10	0	5·773	∞

Of Vis Viva and Momentum.

The *mechanical effect*, or, as it has been appropriately termed, the *work* which a moving force performs, is measured by the weight which it moves through a given space. We have already explained, that when a pressure is applied to a body free to move, and continued for some definite time, a certain velocity will be imparted to that body, and the amount of that velocity will be in direct proportion to the time that the pressure has continued to act. Now the mechanical effect, or work which has been expended in thus imparting motion to the body, has not been lost, but has been accumulated in that body, and will be reproduced upon any force being opposed to the body's motion in overcoming such resisting forces, and the body will

not be brought to a state of rest until it has performed an amount of work precisely equal to that originally expended upon it in acquiring its motion. The work thus accumulated in a moving body, and ready to be imparted in overcoming any force opposed to its motion, is equal to half its *vis viva,* or living force, and is directly proportional to the square of its velocity*; that is, the amount of work which two bodies of the same weight, but moving, the one with double the velocity of the other, would perform in being brought to a state of rest, would be four times as great in the case of the quicker moving body as in that of the slower. But if the resisting force, in overcoming which the vis viva of the moving bodies is supposed to be expended, be uniform in its action, then will the time occupied by it in bringing the quicker moving body to a state of rest be just double that required in the case of the slower; and therefore, if we only consider the work which the two moving bodies are capable of performing in the *same time*, which amount is termed their *momentum*, it will be only proportional to their velocity. By way of recapitulation, then, in order to render the matter quite clear, the force of a moving body, or the work which it will perform *in a given time* (that is, its

* If w represent the weight of a body, v its velocity in feet per second, V its *vis viva,* and g the force of gravity, equal $32\frac{1}{6}$; then we have for the *vis viva* of a moving body,

$$V = \frac{1}{g} w v^2.$$

momentum), varies as its *velocity* multiplied by its weight; but its whole accumulated force, or the total amount of work which it will perform, *no matter in what time*, in being brought to a *state of rest* (that is, half its *vis viva*), varies as the *square of its velocity* multiplied by its weight. In order to illustrate this, let us suppose a railway train, of a certain weight, in motion upon a perfectly level and straight railway, and let us assume that the resistances opposed to its motion are the same, whatever may be its velocity, the practical incorrectness of this assumption not affecting our present object. Imagine the velocity of the train to be fifteen miles per hour, and let it be desired to bring it to a state of rest at a station which it is approaching; suppose that the engine driver, judging from experience, shuts off the steam at a distance of a mile from the station, and that the resistance experienced by the train in moving over this mile is just sufficient to bring it to rest at the station, the time occupied in passing over the mile being six minutes. Now if we again suppose the same train to be moving with a velocity of thirty miles per hour, and it be desired to stop at the station, then, the resistances being the same as before, it will in this case be necessary to shut off the steam at a distance of four miles from the station, in order that it may be brought to a state of rest there, and the time which the train will occupy in passing over these four miles will be twelve minutes. Again, let

two bodies, both of the same weight, be projected upwards, one with double the velocity of the other, and suppose the resistance of the air removed, and only the force of gravitation, perfectly uniform in its action, to be opposed to the motion of the bodies; then will the body projected with twice the velocity rise to four times the height, against the same resistance, before being brought to a state of rest, but it will occupy, in doing so, twice the time similarly occupied by the slower body.

Motion Uniformly Accelerated.

The following propositions express those relations between the spaces, velocities, and times of bodies moving under the action of constant forces, which are of most frequent and general application *.

The velocities generated in a body, in a given time, by the action of a constant force, are directly proportional to the amount of that force.

* If v represent the velocity of a body in feet per second, moving under the influence of the uniform force f, and s the space which it passes over in any time t, the following formulæ express all the relations between those quantities:—

$$v = ft = \frac{2s}{t} = \sqrt{2fs}$$

$$f = \frac{v}{t} = \frac{2s}{t^2} = \frac{v^2}{2s}$$

$$s = \frac{tv}{2} = \frac{ft^2}{2} = \frac{v^2}{2f}$$

$$t = \frac{v}{f} = \frac{2s}{v} = \sqrt{\frac{2s}{f}}.$$

The velocity generated in a body by the action of a constant force, at the end of any given time, is directly proportional to that time.

The spaces passed over in each successive second (or other equal portion of time) by a body under the action of a constant force, are directly proportional to the series of odd integers, 1, 3, 5, 7, 9, &c.

The space passed over by a body, under the action of a constant force, from the commencement of its motion, is directly proportional to the square of the time which it has been in motion.

The velocity which a body will acquire in moving over a certain space, under the action of a constant force, is directly proportional to the square root of that space.

The space passed over by a body, under the action of a constant force, from the commencement of its motion, is half that which it would have described in the same time had its velocity been constant and equal to its final velocity.

In order to exhibit these relations at one view, and to render their connection perfectly well understood, we subjoin a table showing the velocity generated in, and the space described by, a body under the action of a constant force for certain portions of time, and also the spaces passed over by the body in each successive portion of time.

Time of the force's action.	Velocity generated in the body.	Spaces described in the whole time.	Spaces described in each successive portion of time.
1	2	1	1
2	4	4	3
3	6	9	5
4	8	16	7
5	10	25	9
6	12	36	11
7	14	49	13

Motion under the Influence of Gravity.

The force of gravity being constantly the same, both in its direction and amount*, has been universally employed as the unit of measure for all other forces, or the standard with which all other forces are compared. Its actual amount in the latitude of London, as measured by careful experiment, is such that it would cause a body to fall through a space of 386·289 inches, or $32\frac{1}{6}$ feet nearly, in the first second of time, supposing the body to fall in vacuo, or to experience no resistance in its passage through the air.

In order to determine the *space* which a body falling freely by the action of gravity would describe in a given time, we must multiply the square of the time in seconds by $16\frac{1}{12}$ (or, as an approximation

* The force of gravity is not actually constant, as it varies in proportion to the square of the distance from the earth's center; but this difference is so small, that if the force of gravity at the earth's surface be represented by ·10000, the force a mile above the surface would be ·9994.

only, simply by 16); the product will be the space fallen through by the body, in feet. To determine the *time* which a body would occupy in falling from a given height, we must divide the square root of the height in feet by 4; the quotient will be the time occupied in seconds. To determine the *velocity* which a body exposed to the action of gravity for a *given time* would acquire, multiply the time in seconds by $32\frac{1}{6}$, and the product will be the velocity in feet per second; or to determine the *velocity* acquired by a body in falling from a *given height*, multiply the square root of the height in feet by $8\frac{1}{24}$ (or, as an approximation, simply by 8), and the product will be the velocity of the body in feet per second*.

The following table, constructed on the same principle as that given above for *any force whatever*, contains the actual numerical values of the several quantities for a body falling freely by the action of the *force of gravity*.

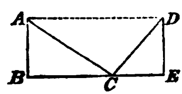
Time, in seconds, of the body's falling.	Velocity acquired by the body in feet per second.	Space, in feet, fallen through by the body in the whole time.	Space, in feet, fallen through by the body in each second.
1	$32\frac{1}{6}$	$16\frac{1}{12}$	$16\frac{1}{12}$
2	$64\frac{1}{3}$	$64\frac{1}{3}$	$48\frac{1}{4}$
3	$96\frac{1}{2}$	$144\frac{3}{4}$	$80\frac{5}{12}$
4	$128\frac{2}{3}$	$257\frac{1}{3}$	$112\frac{7}{12}$
5	$160\frac{5}{6}$	$402\frac{1}{12}$	$144\frac{3}{4}$
6	193	579	$176\frac{11}{12}$
7	$225\frac{1}{6}$	$788\frac{1}{12}$	$209\frac{1}{12}$

* If g or $32\frac{1}{6}$ be substituted for f in the formulæ given at the foot of page 36, they will express the relations between the spaces, velocities and times of bodies moving under the influence of gravity.

Motion down Inclined Planes.

When a body by the action of gravity is made to move down an inclined plane, the accelerating force is diminished in the ratio of the length of the inclined plane to its height, and consequently the time occupied by the descent is increased in the same proportion; the velocity of the body, however, upon reaching the bottom of the incline, is the same as if it had fallen freely through the height of the inclined plane, and is quite independent of the length of the plane or of its inclination, the effects of friction being disregarded. Thus, let A C and C D, figure 12, be two inclined planes, both having the same vertical height A B or D E, but differing in length, and consequently in their rate of inclination; now the gravitating force down the inclined plane A C, would be to the natural force of gravity, as the height of the plane A B is to its length A C, and the time which a body would take in descending the incline, would be to that in which it would freely fall through the height A B, as the length A C is to the height A B; in like manner the force down the incline D C would be to the force of gravity, as its height D E is to its length D C, and the time of a body's descent to the time in falling through the same height, as the length D C is to the height D E: but the velocity acquired by the body in descending the inclines would, in both cases, be the same

Fig. 12.



as that which it would have acquired in falling freely by the action of gravity through the vertical height A B or D E of the inclines.

Friction.

We have hitherto only considered the motion of bodies as influenced by the resistance offered by their own inertia; there are, however, in practice many other causes of resistance which oppose the motion of bodies, the principal of which are those arising from friction, and the resistance caused by the medium through which the body moves, usually either air or water, and the amount and effects of which resistances we will proceed briefly to examine.

We have already stated, that did the air offer no resistance to the motion of bodies, and were there no friction, then would the smallest conçeivable force be sufficient to cause *some motion* in a body however large; that is, it would cause it to pass from a state of rest to one of motion, although if the force were very small and the weight of the body considerable, it would require to be applied fo. a great length of time in order to impart to the body a high velocity. Now we know that, in practice, some considerable force is required to put a body of any weight in motion, and the force so required merely to change the state of the body from rest to motion is the measure of the friction of the body against those substances with which it may

be in contact. Again, a certain velocity having been imparted to a body, we stated that it would continue to move for ever without the application of any further force; but we know that, in practice, a certain constant force would be required to continue the motion of a body undiminished, and such force is the measure of the friction caused by the motion of the body. Now we have here two different species of friction, that arising from the mere contact of the surfaces, which opposes the commencement of motion, and which must be overcome before the body will move at all; and that which arises from the two surfaces rubbing against or moving over each other, which is continually acting upon the body during its motion, and requires the application of a constant force to overcome it, and maintain the body's velocity undiminished. The first of these has been termed the *friction of quiescence*, and the latter the *friction of motion*.

The amount of friction varies with the nature of the surfaces in contact, or rubbing against each other, and may be greatly modified and reduced by the interposition of certain substances, such as tallow and oil, between the two surfaces; these substances are termed *unguents*. It has been found that the amount of friction is entirely independent of the extent of the two rubbing surfaces, or of the velocity with which they move upon each other; but that it varies directly as the force with which the two surfaces are pressed together, or that, sup-

posing the surfaces to remain the same, the friction would increase in the same proportion as the pressure upon the surfaces was increased, so that one would always bear the same ratio to the other. The *constant ratio* thus subsisting between the weight and the friction for the same two surfaces under the same circumstances, whatever that weight may be (within certain limits), has been termed the *coefficient of friction*, and its values for several different substances, are exhibited in the subjoined table.

M. Morin's Experiments on the Friction of Surfaces in Motion on each other.

Substances in Contact.	Coefficient of Friction.	Limiting Angle of Resistance.
Hard calcareous stone, on hard calcareous stone	·64	32° 37′
Soft calcareous stone, on soft calcareous stone	·38	20 49
Oak on oak, (fibres parallel) . .	·48	25 39
Id. (fibres perpendicular) .	·34	18 47
Oak and elm on cast iron . .	·38	20 49
Elm on oak	·45	24 14
Iron on oak	·62	31 48
„ on elm	·25	14 2
„ on iron	·14	7 58
„ on cast iron and brass . .	·18	10 12
Cast iron on oak	·49	26 33
„ on elm	·20	11 19
„ on cast iron	·15	8 32
Brass on brass	·20	11 19
„ on cast iron	·22	12 25
„ on iron	·16	9 6
Copper on oak	·62	31 48
Leather belts on wooden pullies .	·47	25 11
„ on cast iron pullies .	·28	15 39

All the above values are without the interposition of any unguent.

The coefficients for stones depend greatly upon their hardness and the smoothness of their beds, and vary from ·58 to ·84, the limiting angles of resistance varying from 30° to 40°. The values of the coefficient of friction, and of the limiting angle of resistance for different kinds of earth, will be found at page 69.

When the quantity of the unguent is sufficient to cause an entire separation between the two surfaces, it has been determined by the experiments of M. Morin that with either hog's lard, olive oil, or tallow, the coefficient of friction for wood on wood, wood on metal, metal on wood, or metal on metal, is nearly constant, and is between ·07 and ·08; the only exception being in the case of metal on metal with *tallow* as an unguent, when the coefficient was found to be about ·10.

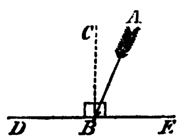
The friction of quiescence has been found to increase when the surfaces have remained in contact for a considerable length of time. It has also been found that the friction of quiescence may be removed or reduced to the state of the friction of motion, by giving a sufficient *shock* to the two surfaces in contact.

Fig. 13.

If a body be situated on an inclined plane, the length of whose base C B, figure 13, bears the same proportion to its height A C as the

weight of the body does to the coefficient of its friction against the surface of the plane, then the body will be upon the point of sliding down the plane; and if any motion were imparted to it, it would continue to move as if entirely uninfluenced by friction. If a body placed on a plane surface D E, figure 14, be acted upon by a force whose direction is such that the angle A B C, which it makes with the perpendicular to the surface D E, is the same as the angle A B C* of the inclined plane, figure 13, then will the body be upon the point of sliding along the surface, whatever may be the amount of the force, and if the angle A B C be increased by ever so small an amount, motion will ensue. The angle A B C has been termed by Professor Moseley the *limiting angle of resistance;* its values for several different substances are contained in the third column of the table at page 43. This proposition is of great importance in the investigation of the stability of walls and arches.

Fig. 14.



Resistance of the Air.

We have next to consider the resistance which the air offers to the motion of a body passing through it. The amount of this resistance depends

* The angle A B C, or the limiting angle of resistance, is that angle whose tangent equals the coefficient of friction, radius being unity.

upon the form of the body in motion, but we shall confine ourselves to the case in which the body presents a flat surface. Under these circumstances, the amount of resistance has been found to be proportional to the area of the surface exposed, and to increase as the square of the velocity with which the body moves; it also depends upon the depth or thickness of the body, the resistance being greater against a thin plate than against a cube or prism, with the same front surface. The resistance of the air in pounds against a thin surface is found by multiplying the area of the surface in square feet by the square of the velocity in feet per second, and by ·0017; if the body is a cube instead of a plate, the resistance equals the area of the front surface multiplied by the square of the velocity and by ·0014; and if a prism whose length is three times the side of its front surface, the resistance equals the area of the front surface multiplied by the square of its velocity and by ·0013.

Resistance of Water.

The resistance which water offers to the motion of a plane surface follows the same law as that of air; that is, it is proportional to the area of the surface, and to the square of its velocity. The amount of this resistance, in pounds, will be found by multiplying the area of the surface in square feet by the square of its velocity in feet per second, and by ·976.

It has been observed by Dubuat, both in the case

of air and water, that the resistance to a body moving through them with a certain velocity is less than the resistance of the air or water when moving with the same velocity against the body at rest.

CHAPTER III.

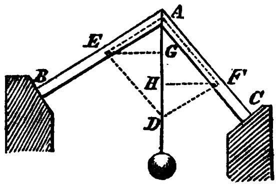
GENERAL CONSTRUCTION.

MECHANICAL PRINCIPLES OF CONSTRUCTION.

Equilibrium of an Assemblage of Beams.

We shall now proceed to the practical application of the principles which have been detailed in the preceding chapter; and in doing so shall commence with the simplest case, that of two beams, A B and A C, figure 15, resting against each other at their upper extremities, and against two walls at their lower, and sustaining a weight suspended from A; and we shall proceed to examine the strains, both on the beams and on the walls, occasioned by this weight.

Fig. 15.

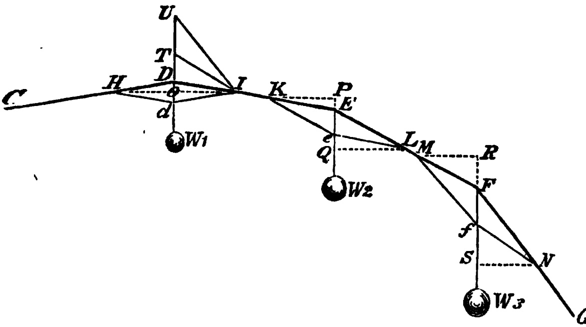


Let the weight suspended from A be represented by the line A D; draw D E parallel to A C, and D F parallel to A B, also E G and F H perpendicular to A D; then, by the principle of the parallelogram of pressures explained at page 11, the strain on A B in the direction of its length is represented by A E, and that on A C by A F.

Now, each of these strains may be resolved into two others, one acting vertically upon the wall in the direction of gravity, and the other acting horizontally, and tending to push the two walls asunder. Thus A E may be resolved into the strain A G acting vertically, and E G horizontally; and A F into the strain A H acting vertically, and H F horizontally. Now, the two triangles A E G and D F H being equal, the similar sides H D and A G are equal; and therefore the two vertical strains A G and A H are together equal to A D, or the weight suspended from A; that is, the whole weight borne by both walls is equal to that suspended from A; but the amount borne by each wall depends upon the relative inclination of the two beams. It must further be observed that the lines E G and H F, representing the strains acting horizontally, are equal; that is, whatever may be the relative inclination of the two beams, their horizontal thrust against the walls is the same, and is equal to that with which they press against each other at A.

Let fig. 16 represent a system of framing, composed of four beams, united together in such a manner as to form a polygon, and so connected at the points C, D, E, F, and G, as to admit of motion about those points; so that the beams are not rigidly fixed in the position shown in the diagram, but are free to assume any other form which any external force applied to them might tend to produce. Further, let us suppose weights W_1, W_2, and W_3, to be sus-

Fig. 16.



pended from the points D, E, and F, and so proportioned to each other that the framing, under the influence of the strains which they produce, is in equilibrium, or has no tendency to alter its form. Let the lines D *d*, E *e*, and F *f*, represent the weights applied at the points D, E, and F, and let each of those weights be resolved into the strains which they produce in the two contiguous beams, by constructing the parallelograms D H *d* I, E K *e* L, and F M *f* N. Then the lines D I and E K will represent the two strains acting in opposite directions upon the beam D E, and E L and F M will, in like manner, represent the two strains acting similarly upon E F. Now, since the whole system is in equilibrium, and all its parts free to move, it follows that each of its several parts, and therefore the beams D E and E F, must also be in equilibrium; such being the case, it results that the strain represented by D I must be equal to that represented by E K, otherwise the beam D E would

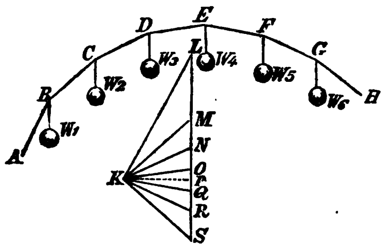
move in the direction of the greater strain, and, in like manner, the strain E L must be equal to F M. Now, let each of these strains be resolved into two others, acting vertically and horizontally; then will the latter be represented by the lines O I, P K, Q L, R M, and S N. Now, since D I, E K, and *e* L are all equal, and the triangles D I O, E K P, and *e* L Q are similar, the lines O I, P K, and Q L, and therefore the strains which they represent, must all be equal. Again, since E L, F M, and *f* N are all equal, and the triangles E L Q, F M R, and *f* N S are similar, the lines Q L, R M, and S N, and therefore the strains which they represent, must all be equal. *That is, in a system of polygonal framing, whose several parts are in equilibrium, the* horizontal *strain or thrust at all the joints is the same.*

Let us now draw through I the line I T parallel to E F, and the line I U parallel to F G; then, since O I is equal to Q L, and (T I being parallel to E L) the angle E L Q similar to T I O, it follows that T I must be equal to E L. In like manner, S N being equal to O I, and the angle F N S similar to U I O, U I must be equal to F N. Since, then, the lines E L and F N represent the strains on the beams E F and F G, so do also the lines T I and U I; *therefore in a system of polygonal framing whose several parts are in equilibrium, the strains on the several beams,* in the direction of their lengths, *are represented by lines drawn through a given point parallel to those directions, and limited by a given vertical line.*

In like manner, it may be shown that the portions U T and T D of the vertical line U *d*, cut off by the lines drawn parallel to the several beams, are equal to the lines F *f* and E *e*, which represent the weights suspended from those beams.

From the foregoing investigation, we derive an easy method of determining the several strains in any system of polygonal framing whose parts are in equilibrium. Let fig. 17 represent such a system, kept

Fig. 17.



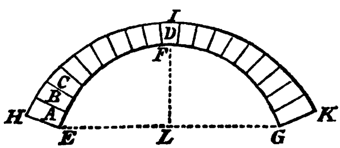
in equilibrium by the weights w_1, w_2, &c., suspended from its angles; then draw the vertical line L S, and divide it into portions L M, M N, N O, &c., proportional to the weights w_1, w_2, w_3, &c.; through the points L, M, N, &c., draw lines parallel to the directions of the several beams A B, B C, C D, &c.; then, if the system is in equilibrium, all these lines will intersect in the common point K: draw K P perpendicular to L S, then will K P represent the horizontal thrust against each of the joints B, C, D, &c.; the lines L K, M K, N K, &c., the strains in the direction of their length, of those beams which they are severally

parallel to; and by the construction, L M, M N, &c., will represent the vertical weights on the several angles, the whole line L S being equal to the sum of all the weights together*.

Equilibrium of Arches.

The foregoing principles contain all that is necessary to the determination of the equilibrium of arches. An *arch* may be defined to be an assemblage of wedge-formed bodies, the first and last of which are sustained by a support or *abutment*, while the intermediate ones derive support and are sustained in their positions by their mutual pressure, and by the adhesion of cement interposed between their surfaces. The wedge-formed bodies A, B, &c., fig. 18, thus sustained, are termed *voussoirs*, the center one D, or that in the highest part or *crown* of the arch, being called the *key-stone;* the inferior surface of the arch E F G is called its *intrados*, or sometimes its *soffit;* but this latter term

Fig. 18.

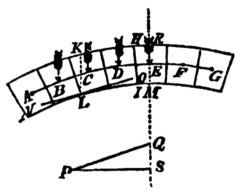


* If the line K P, fig. 17, be considered as *radius*, then will the lines L K, M K, &c., be the *secants*, and L P, M P, &c., the *tangents*, of the angles L K P, M K P, &c. That is, if we make the horizontal strain, in any system of polygonal framing whose parts are in equilibrium, equal to radius, then will the strain upon any bar of the polygon, in the direction of its length, be equal to the secant of the angle which it makes with the horizontal; and the weight suspended from any joint of the polygon will be equal to the difference of the tangents of the angles which the two bars meeting at that joint make with the horizontal.

is sometimes restricted to mean only the under surface of the arch at its key-stone or crown F; the exterior surface H I K is called its *extrados*. The points E and G, where the *intrados* meets the abutment, are called the *springings*, their horizontal distance E G the *span*, and the distance F L the *rise* of the arch.

Let A, B, C, &c., fig. 19, be the separate stones or voussoirs of an arch whose several parts are in equilibrium. Now, each stone is acted upon by three forces, namely, the weight of itself and the load above it acting in a vertical direction, and the pressure of each of the two contiguous stones acting in directions perpendicular to their surfaces of mutual contact; then, since these forces must all be in equilibrium, their lines of direction must all intersect in some common point within the stone.

Fig. 19.



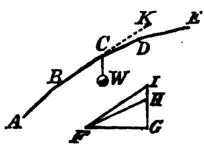
Let A, B, C, &c., represent these points in the several stones composing the arch shown in the figure; then if lines A B, B C, C D, &c., be drawn connecting these points, they will represent the directions in which the stones press on each other, and the line A B C, &c., is termed the *line of pressure* of the arch. Now, although the pressure of one stone upon its neighbour, as of E upon D, is actually spread over the whole surface of the joint H I, we may, without in any way affecting the question under considera-

tion, suppose the whole pressure collected in the point in which the line of pressure cuts the joint H I, and similarly of all the other stones; so that if we conceive the whole weight of each stone, and of the load which it supports, to be collected in (or, which is the same thing, suspended from) the points A, B, C, &c., and those points to be connected by inflexible bars A B, B C, C D, &c. (themselves devoid of weight), we shall in nowise alter or disturb the state of equilibrium of the arch.

An arch, thus considered, is precisely similar to a polygonal framing whose sides are A B, B C, C D, &c., and therefore all the principles which we have deduced in the investigation of the latter may be applied to the arch. This application, however, involves the use of mathematical formulæ and terms which cannot be here introduced, and we must, therefore, content ourselves with stating the conclusions to which they lead; which conclusions are, that for an arch to be in equilibrium, the *vertical* depth of the arch at any point must be inversely proportional to the radius of curvature of the arch at that point, and directly proportional to the cube of the line drawn parallel to the tangent to the arch at that point. Thus, supposing the arch in figure 19 to be in equilibrium, draw the horizontal line P S parallel to the tangent to the arch at the crown M, and through P draw the line P Q parallel to N O the tangent to the arch at any point L; then the vertical depth R M at the crown is to the vertical depth

KL at any point L, as the cube of the line PS, divided by the radius of the arch at M, is to the cube of the line PQ divided by the radius of the arch at L*.

Fig. 19*.



* The demonstration of the proposition contained above is as follows:—Let ABCDE, fig. 19*, be a portion of the line of pressure of an arch, considered as a system of polygonal framing. Now we have shown, page 51, that in such a framing, if the weight on any angle C is represented by the vertical line IH, then will the pressures in the directions of the two bars BC and CD, meeting at that angle, be represented by the lines IF and FH drawn parallel to the same. In any triangle the sides are proportional to the sines of their opposite angles; therefore IH : IF : : sin IFH : sin FHI; but the sine of the angle FHI is the same as the sine of its supplement FHG, and the sine of the angle FHG is equal to the cosine of its complement HFG; also the line IF is the secant of the angle IFG, therefore IH : sec IFG : : sin IFH : cos HFG,

$$\text{or } IH = \sin IFH. \sec IFG. \frac{1}{\cos HFG};$$

but $\frac{1}{\cos HFG}$ is equal to sec HFG, therefore

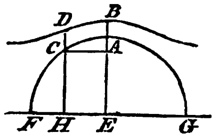
$$IH = \sin IFH. \sec IFG. \sec HFG.$$

Now, in reality, the line of pressure ABCDE is a curved line, and therefore the sides of the polygon must be supposed to be exceedingly small in order that it may more nearly coincide with the curve; in which case, the angle KCD, equal to the angle IFH, becomes the angle of contact between the curve and its tangent, which being exceedingly small, is directly proportional to its sine, and inversely proportional to the radius of curvature of the line of pressure at the point C, therefore sin IFH is proportional to $\frac{1}{R}$, R representing the radius of curvature at C. Further, the angle IFH, the difference between the angles IFG and HFG, being exceedingly small, the two latter may be considered equal, and therefore sec IFG may be substituted for sec HFG. Making these substitutions in the equation above, it becomes

$$IH = \frac{\sec^2 IFG}{R}.$$

These conditions are fulfilled in a circular arch, by making the vertical depth D C, figure 20, at any point C, equal to the depth of the key-stone A B, multiplied by the cube of the radius A E, and divided by the cube of the vertical height C H of the point C above the diameter F G. In an ellipse they are fulfilled when the vertical

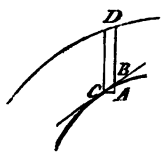
Fig. 20.



Or, since I H represents the vertical weight on C, and I F G the angle which the tangent to the curve at C makes with the horizontal, the vertical load or weight *on any point of an arch in equilibrium is inversely proportional to its radius of curvature at that point, and directly proportional to the square of the secant of the angle which the tangent to the curve at that point makes with the horizontal.*

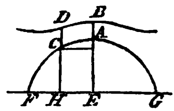
Now, the vertical load on any small portion of the arch C B, figure 20*, is proportional to its base C A, multiplied by its height C D, and C A : C B :: rad : sec B C A, or radius being equal to unity, $\mathrm{CA} = \frac{\mathrm{CB}}{\sec \mathrm{BCA}}$; then, supposing the weight to be everywhere equal, C D must be inversely proportional to C A, that is, $\mathrm{CD} = \frac{\sec \mathrm{BCA}}{\mathrm{CB}}$, or since C B is everywhere equal C D is simply proportional to sec B C A; but B C A is the angle which the tangent to the curve at the point C makes with the horizontal, as is also I F G, *fig.* 19*, therefore sec B C A is equal to sec I F G, and if the vertical weight upon the arch were everywhere required to be the same, C D would be proportional to sec I F G; but it has been shown that the weight should be proportional to $\frac{\sec^2 \mathrm{IFG}}{\mathrm{R}}$, and therefore C D must be proportional to $\frac{\sec^3 \mathrm{IFG}}{\mathrm{R}}$; *that is, the* vertical height or thickness *of an arch in equilibrium, at any point, must be inversely proportional to the radius of curvature of the arch at that point, and directly proportional to the cube of the secant of the angle which the tangent to the curve at that point makes with the horizontal.*

Fig. 20*.



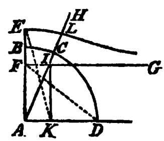
depth D C, figure 21, over any point C, is equal to the depth of the key-stone A B, multiplied by the cube of A E, half the shortest axis of the ellipse, and divided by the cube of the vertical height C H of the point C above the longer axis F G of the ellipse.

Fig. 21.



The extrados of a circular arch, whose parts are all in equilibrium, may also be determined geometrically in the following manner:—Let B C D, fig. 22, be half a semicircular arch, whose center is A, and B E the depth of its key-stone; then in the vertical line A B take the point F, such that the distance D F is equal to A E, and through F draw the horizontal line F G. Then, through any point C, draw the line A H from the center A, and through I, the point in which it cuts F G, draw I K perpendicular to A D; then make A L equal to K E, and the point L will be a point in the extrados of the arch, any number of points in which may be determined in a similar manner.

Fig. 22.

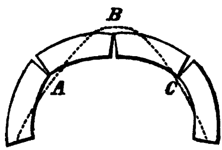


An arch in which the above conditions are fulfilled is in a perfect state of equilibrium, every portion of it is equally strained, and no part has a tendency to yield before another. If in an arch so circumstanced, all the joints of the voussoirs were perpendicular to the inner surface, or intrados of the arch, then would the line of pressure pass

through the *center* of every joint, and would cut them all in a direction perpendicular to each. In practice, however, this state of things seldom, if ever, occurs, the line of pressure neither passing through the center of the joints of an arch, nor being perpendicular to them in direction; it is, therefore, desirable to examine to what extent these conditions may be deviated from without endangering the stability of the structure. When an arch is in a state of perfect equilibrium, if we suppose its abutments incapable of yielding, it can only fail in consequence of the crushing of its material, the cohesive power of which is then the limit of the strength of the arch. When, however, an arch is not in a state of equilibrium, it may fail in two ways: in the first case, the stones may slide upon or slip past each other, and so become displaced; and, in the second case, they may yield by turning upon some of the joints, the arch separating into three or four large portions, as in figures 23 and 24, and turning on the inner and outer edges of certain of the joints. Now, the voussoirs of the arch cannot slide upon each other unless the angle which the line of pressure makes with a perpendicular to the joint is equal to, or greater than, the *limiting angle of resistance* for the material of which the arch is composed, which, as stated at page 44, is usually about 30° for stone; and as this is very much greater than the angle which the line of pressure ever makes with the perpendicular to

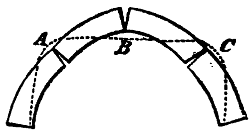
the joint, an arch may be considered in no danger of giving way from the *slipping* of its voussoirs; to which we may add, that the adhesion of the cement interposed between the stones, as also the joggles frequently inserted, are an additional security against the failure of an arch from this cause. The second mode of failure, which is also the most usual, takes place whenever the line of pressure deviates so far from the position of equilibrium as to pass entirely out of the substance of the arch, so as not to cut the joints at all. The more the line of pressure deviates from the center of the joints, the less will be the stability of the arch; but so long as it continues to cut the joints no motion can take place; the moment, however, that it passes without the joint, motion will take place, the two voussoirs will turn upon their edges nearest to the line of pressure, and the arch will fall. Thus, in figure 23, if, by placing too great a load upon the crown of the arch, we alter the form of the line of pressure until it rises above the extrados at B, and falls within the intrados at the points A and C, the arch will separate at the nearest joints to those points into four portions, which will turn upon their inner edges at A and C, and upon their outer edges at B, the arch sinking at the crown and rising at the haunches. If, however, there be a deficiency of

Fig. 23.



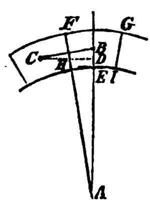
weight at the crown, then the line of pressure will fall within the intrados at B, figure 24, and rise above the extrados at A and C, the arch separating as in the former case, but now turning about the outer edges at A and C, and about the inner edges at B, the crown rising and the haunches falling in. We see, then, that when we deviate so far from the arch of equilibrium as to cause the line of pressure to approach either the intrados or extrados of the arch, we begin to endanger its stability, actual contact with either being the ultimate limit; and the stability of the arch being greater, as we make the line of pressure approach nearer to the center of the joints.

Fig. 24.



When an arch has all its parts in equilibrium, it has been shown, page 50, that the horizontal strain on every joint is the same, and therefore the perpendicular pressure, tending to crush the key-stone of the arch, is equal to the horizontal thrust against its abutment. In order to determine the amount of this strain, let F G H I, fig. 25, represent the center voussoir or key-stone of an arch whose center is A; let C B be the direction of the line of pressure of this voussoir on its neighbour, perpendicular to the joint F H; and let half the weight of the key-stone and the load which it supports

Fig. 25.



be represented by the line B D; then it has been shown that the horizontal pressure on the joint F H will be represented by C D; that is, as B D : the weight on half the key-stone :: C D : the horizontal pressure against the same. Now, the triangle A H E is similar to the triangle C B D, and therefore H E : B D :: A E : C D; further, the weight on half the key-stone is equal to half its breadth in feet, or H E, multiplied by the weight on every foot; also A E is the radius of the arch at the crown; therefore H E : H E multiplied by the weight on every foot of the key-stone :: the radius of the arch : the horizontal pressure against the key-stone; *or, in an arch in equilibrium, the* horizontal pressure on the key-stone *is equal to the weight on a foot of the surface of the same, multiplied by the radius of the arch in feet.*

The power of an arch to resist the horizontal strain at the crown is proportional to the depth of the key-stone, and to the cohesive power of the material of which the arch is composed. The *stability of an arch* is, therefore, directly proportional to the depth of its key-stone, multiplied by the cohesive power of the material, and is inversely proportional to its radius of curvature multiplied by the weight on every foot of its surface*.

* Let R be put for the radius of curvature of an arch at its crown, d for the depth of its key-stone, and b for the breadth of the arch, all in feet; also let w equal the vertical weight on every square foot of the key-stone, including its own weight, P equal the horizontal pressure upon the key-stone, and c the weight required to crush a square foot of the material of the arch, all in pounds; then

$$P = Rbw; \text{ and}$$

In arches of timber or iron the construction is usually such that the arch is rigid, or incapable of altering its form; and therefore no regard is paid to the direction of the line of pressure, or to the equilibration of the arch. In this case, the arch may be considered as composed of two parts, resting upon the two abutments, and against each other at the crown; and, in order to determine the stability of the structure, it is only necessary to consider the mutual

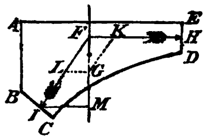
the stability of the arch will be proportional to $\frac{dc}{Rw}$, which expresses the number of times that the strain upon the arch is less than that which would cause it to yield by crushing at the key-stone.

The following table exhibits the approximate value of $\frac{dc}{Rw}$ for some of the principal bridges.

Name and Situation of Bridge.	Radius of Curvature of the Arch, in feet, at the Crown.	Value of $\frac{dc}{Rw}$, or number of times that the pressure on the key-stone must be increased to crush it.
	Feet.	
Bridge carrying the Great Western Railway over the Thames at Maidenhead	169	3
Neuilly Bridge, over the Seine, at Paris	260	5
Bridge of the Holy Trinity, over the Arno, at Florence	172·63	21
Bridge over the Dee, at Chester .	140	22
London Bridge, over the Thames .	162	40
Bridge over the Dora Riparia, near Turin	160	44
Bridge of St. Maxence, over the Oise.	121	53
Waterloo Bridge, over the Thames .	112·5	68

pressure of the two parts against each other acting horizontally at the crown, and the pressure of each upon its abutment acting perpendicular to the direction of the same. Thus, suppose A B C D E, fig. 26, to represent half an iron bridge, G being its center of gravity, and F G M the vertical direction in which its weight acts; draw F H through the center of the vertical joint E D perpendicular to the same, and F I through the center of the springing B C and perpendicular to it; then, in order that the arch may be properly supported, these two lines should intersect in some point F, in the vertical line F M passing through the center of gravity G; and such being the case, if F G represent the weight of the half arch A B C D E, then will F K represent the pressure acting in the direction F H upon the joint E D, and F L will represent the pressure acting in the direction F I upon the abutment B C. Then, by similar triangles, F K : I M :: F G : F M, and I M may be taken as equal to the horizontal distance of the center of gravity of half the arch from its springing, and F M as equal to the rise of the arch, or the vertical height of its crown above the springing line; *therefore, as the horizontal distance of the center of gravity of half the arch from its springing is to the rise of the arch, so is the* horizontal thrust, either against the abutment or at the crown, *to the weight of half the arch.*

Fig. 26.

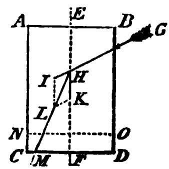


Equilibrium of Abutments and Walls.

We have next to examine the conditions of the stability of piers, abutments, or walls, sustaining some external load or strain, such as the thrust of an arch, or the pressure of earth or water. Walls and abutments are usually exposed to two forces—their own weight acting in a vertical direction through their center of gravity, and the pressure occasioned by the extraneous load which they have to sustain; and upon the magnitude and direction of the resultant of these pressures the stability of the structure depends. They may yield or give way in three different ways: namely, the wall or abutment may separate into two portions, one sliding or slipping upon the other; or it may similarly separate, and the upper portion turn over about one or other of its edges; or the material of the wall may be crushed by the pressure exceeding its cohesion. Or, in case the wall or abutment itself is too strong to be broken or crushed, it may still yield in any one of the above ways, by either sliding upon the surface of the ground, or turning over upon one of its lower edges, or from the ground yielding under the pressure. For examples, let A B C D, figs. 27 and 28, represent two walls, each sustaining a pressure acting in the direction G I; let E F be the vertical line passing through the center of gravity, H the point in which it is intersected by the direction of the pressure; also let H K represent the weight of the wall, and H I the amount of the pressure; then the diagonal H L will represent their

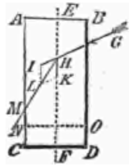
resultant acting in the direction H M. Now, let N O, fig. 27, be a joint in the masonry of the wall; then (neglecting the adhesion of the cement) if the angle M H F, which the resultant makes with the perpendicular, be greater than the limiting angle of resistance, the upper portion of the wall A B N O will slide upon the lower portion N O C D; and if the adhesion of the cement (being now taken into account) is sufficient to prevent the wall separating at N O, then will the whole wall A B C D slide bodily upon the ground in contact with its base C D; if, however, the angle which the resultant H M makes with the perpendicular to the joints is less than the limiting angle of resistance, the wall cannot yield by the sliding of its parts upon each other; and the stability of the wall or abutment will be greatest in this respect when the direction of the resultant H M is perpendicular to all the joints and also to its base C D.

Fig. 27.



If the resultant H M, instead of falling within the base of the wall, cut the side A C, as in fig. 28, then will the wall separate at the nearest joint N O, and the upper portion will be overthrown, turning upon its edge at N; should, however, the adhesion of the cement be sufficient to prevent the separation of any of the joints, then will the whole wall, A B C D, be thrown

Fig. 28.



over bodily, turning on its lower edge C. The wall, however, cannot be overthrown, so long as the resultant keeps within its substance, and cuts the base C D; and its stability in this respect will be the greatest when the resultant passes through the center of its base C D.

If, however, both the foregoing conditions be fulfilled, that is, if the resultant pass through the center of the base, and its direction be perpendicular to the same, the wall or abutment may still give way by the crushing of its material, or by the yielding of the ground on which it stands, if the amount of the resultant pressure is greater than they are either of them capable of supporting.

The external pressures to which walls are most frequently exposed are those occasioned by the thrust of arches or the principals of a roof (both of which we have sufficiently explained the method of determining); and also, in the case of retaining walls, the pressure resulting from earth or water sustained by the wall, which latter case we shall next proceed to consider.

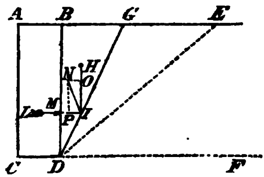
Pressure of Earth or Water against Walls.

When any kind of earth is thrown up into a heap, the sides assume a certain inclination, which is termed the *natural slope*, and is equal to the limiting angle of resistance, or the angle at which a mass of the same earth would commence sliding down its side*.

* See page 45.

When a mass of earth, supported by a wall, as in figure 29, gives way, in consequence of the insufficiency of the wall, it is usually found to separate on some plane D G, the prism of earth B G D sliding down the plane G D, and overthrowing the wall by its pressure against the back B D.

Fig. 29.



Let G D be the inclination at which the earth separates, and let us suppose the mass B G D to be on the point of sliding, or just kept in equilibrium by the resistance of the wall. Now, the two pressures acting upon the mass B G D are its weight acting in the vertical line H I, and the resistance of the wall acting in the direction L I; then, if we represent the former by O I, and the latter by P I, the diagonal N I will be their resultant, and will represent the pressure of the prism B G D upon the plane G D; then, since it is upon the point of sliding down this plane, the angle which N I makes with a perpendicular to the surface of the plane D G must be equal to the limiting angle of resistance. Now, the weight of the mass of earth B G D is equal to B D, multiplied by half B G, and by the weight of a cubic foot; therefore, the more G D is inclined, the longer B G will be, and the greater will be the weight of the earth which the wall has to support, and the length of the line O I which represents it; but the more D G becomes in-

clined the nearer will N I approach to the vertical H I, and therefore the less will be the line P I representing the pressure of the earth against the wall. It must, therefore, follow that there is a certain inclination for the plane D G, which occasions the pressure on the back of the wall to be greater than any other, and this is found to be when the angle B D G is half that which the *natural slope* of the earth D E makes with the vertical, the angle E D F being the limiting angle of resistance*. Now, in this case, it may be shown that the triangle N O I is similar to G B D; and therefore, if B D represent the weight of the mass B G D, B G will represent its pressure against the wall, that is, the weight of the earth is to its pressure against the wall as the height of the wall is to B G; and since the weight of the earth equals the height of the wall, multiplied by half B G, and by the weight of a cubic foot of the earth, *it follows that the* pressure of the earth against the wall *is equal to half the square of B G, multiplied by the weight of a cubic foot of the earth.* With the same earth, B G always bears the same proportion to the height of the wall, which proportion for the different kinds of earth is given in the fourth column of the subjoined table, the height of the wall being taken as unity, and the fifth column contains half the square of this fraction, multiplied by the weight of a cubic foot of the earth. In order, then, to determine the pressure produced against a wall by different kinds of soil, we have only

* Moseley's Mechanical Principles of Engineering, p. 445.

to *multiply the square of the height of the wall in feet by the number contained in the last column of the subjoined table, and the product will be the pressure in pounds, acting horizontally against the back of the wall at a point* (M, fig. 29) one-third *of the height of the wall above its base.*

Nature of the Earth.	Weight of a cubic foot, in pounds.	Limiting angle of Resistance = E D F.		Value of B G, the height of the wall being 1.	Constant multiplier.
		°	′		
Fine dry sand	94	30	0	·577	15·666
	119	40	0	·466	12·938
Loose shingle, perfectly dry	106	39	0	·477	12·058
Common earth, perfectly dry and pulverulent	94	43	10	·433	8·815
The same, slightly moistened, or in its natural state	106	54	0	·325	5·595
Earth the most dense and compact	125	55	0	·315	6·213

The numbers obtained by the foregoing rule represent the *active pressure* which the earth exerts against the wall tending to push it over about the point C, and must not be confounded with the *passive resistance* which it would offer to prevent the wall being overthrown in the contrary direction about the point D. In the first case, when the wall is on the point of moving the mass of earth B G D is about moving *down* the inclined plane D G, pushing the wall before it; while in the second case, when the wall is about to move the same mass is on the point of being pushed *up* the incline. Upon this suppo-

sition the angle B D G becomes equal to the complement of its former value *, and therefore the resistance calculated for this new value of B G would be much greater than before. The result, however, of mathematical reasoning in this case gives a value for this resistance far greater than it would be safe in practice to calculate upon; because the ground not being incompressible would yield from that cause, and allow the wall to move long before the amount of resistance which this calculation would show the ground to be capable of producing had been exerted.

In the case of walls supporting water, such as dock and quay walls, the resultant of the pressure of the water against the whole surface of the wall is a pressure acting horizontally at a point two-thirds of the depth of the water below its surface, and equal in amount to the square of the whole depth of the water in feet, multiplied by 31·25, the product being the pressure in pounds. The same rule will determine the pressure of water against lock gates, or any other vertical surface. The pressure of water increases with its depth, and is equal at any point to the depth in feet, multiplied by $62\frac{1}{2}$ lbs. (the weight of a cubic foot); therefore, to determine the pressure on any surface entirely immersed in water, whatever may be its position, whether vertical, horizontal, or inclined, we have only to multiply the area of the surface in square feet by the depth in feet of its

* Moseley's Mechanical Principles of Engineering, p. 448.

center of gravity below the surface of the water, and by $62\frac{1}{2}$.

In the case of walls sustaining water, the active resistance and the passive pressure are precisely equal.

Equilibrium of Suspension Bridges.

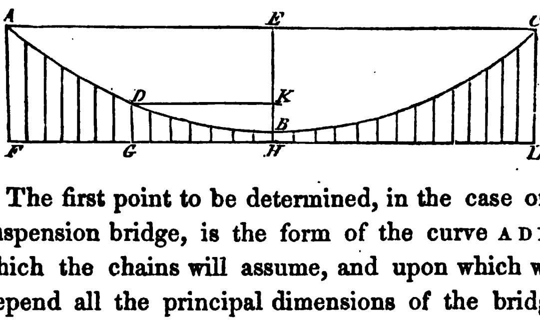
In a suspension bridge, the roadway or platform is suspended from chains, the links of which are straight, by vertical rods, attached to the joints. And as the chains are not rigid, but are capable of altering their form by motion about any of the joints, it follows that, in any position which the chain assumes, its several parts must be in equilibrium. Now a chain, so circumstanced, in no way differs from a polygonal framing, such as is shown in figure 17, supposed to be inverted, excepting that the strains upon the several bars or links, which, in the latter, were thrusts tending to compress the bars, are now tensile strains tending to pull them asunder; and therefore all the properties of the one are common to the other, and the various relations which we have shown to subsist between the weights suspended from the angles, the strains on the several bars or links, and the horizontal strain, in the case of the polygonal framing, similarly subsist in that of the chains of a suspension bridge. The investigation, however, necessary for deducing from these relations rules for determining the proportions of a suspension bridge, that its several parts may be in equilibrium,

involves the use of propositions and terms in mathematics far too abstruse and difficult to be admitted in this place; we must, therefore, content ourselves with pointing out the circumstances affecting their stability, and merely giving rules for proportioning their parts, without attempting their demonstration.

The chains of a suspension bridge have to support three separate loads, which are very differently distributed, namely, their own weight, which varies with the dimensions of the chain and its inclination; the weight of the rods by which the chains and platform are connected, and which varies with their length; and the weight of the platform or roadway with its load, which is usually uniformly distributed. The first suspension bridges which were constructed had their chains made of the same dimensions throughout; but as the tensile or pulling strain upon the different parts of the chain varies greatly, depending, in fact, upon its inclination, as explained at page 50, being greatest at the points where the chains are attached to the piers, and least in the center or lowest point of the chain, it is evident that in so constructing them a superabundance of strength is given to the center portion of the chain, and that the strength of the whole would be increased by taking away some of the metal from those parts of the chain and adding it to the parts more inclined, so proportioning their substance that the cross section of the chain may be in every part proportional to the strain which that part has to sustain.

Let figure 30 represent a suspension bridge, with the roadway or platform F L horizontal, and A D B C being the curve formed by the chains; the points A and C, at which the chain is attached to the piers, are called the *points of suspension;* the horizontal distance A E or E C of these points from the center of the bridge, the *semi-span;* and the vertical distance E B of the lowest point of the chain below the point of suspension, is termed the *deflection.* The term *sectional area of the chains,* at any point, means the surface (measured in square inches), which would be exposed by sawing the chains across at that point.

Fig. 30.



The first point to be determined, in the case of a suspension bridge, is the form of the curve A D B C which the chains will assume, and upon which will depend all the principal dimensions of the bridge. The dimensions which are requisite for determining this are the semi-span A E, the deflection E B, and the distance B H, of the roadway below the lowest point of the chain, or the length of the shortest suspending rod; these being known, any number of points in the curve may be determined by the following rule:—

The Roadway of a Suspension Bridge being Horizontal, to find the Length of the Suspending Rod D G *at any point* D.*

Rule.—Subtract the length of the shortest suspension rod B H from the deflexion E B; multiply the remainder by the square of the horizontal distance D K of the point D from the lowest point B of the chain, and divide by the square of the semi-span A E; to the quotient add the length of the shortest rod B H, and it will give the length of the suspending rod D G.

The curve formed by the chain having been found, it only remains to determine the strains to which each portion of it is exposed, in order that its area in every part may be made proportional to the strain which that part has to sustain. In order to determine these, it is necessary to have, in addition to the dimensions above, the weight of a foot in length of the roadway or platform of the bridge, including the greatest load which it is ever possible that it will have to support. These being known, the following rules will give the dimensions of the chains.

* These rules are deduced from the formulæ given by Professor Moseley in his Mechancial Principles of Engineering, page 547, in which work he has given a very able and complete investigation upon this difficult subject. In the above rules the tensile strain required to break a square inch of wrought iron is taken at 67,200 pounds, the weight of a bar a foot long and an inch square, at 3·3 pounds, and the iron is supposed to be loaded with only a sixth of its breaking weight.

To find the Strain on the lowest point B *of the Chain, and its Sectional Area.*

Rule.—Subtract the length of the shortest suspension rod B H from the deflexion E B; divide twice the remainder by the square of the semi-span A E, and from the quotient subtract ·0003; divide the weight in pounds of a foot in length of the roadway when loaded, by this remainder, and the quotient will be the strain in pounds upon the lowest point B of the chains; and if this strain be multiplied by ·0000893 it will give the sectional area of the chains in square inches, at the same point.

To find the Strain on the Chain, and also its Sectional Area at any point D.

Rule.—Divide twice the vertical height K B of the point D above the lowest point B of the chain by the horizontal distance D K of D from B, and to the square of the quotient add 1; the square root of this sum multiplied by the strain on the chain at B (as found by the rule above) will give the strain upon it at D; and this strain multiplied by ·0000893 will give the sectional area of the chain at the same point in square inches.

We shall illustrate the use of these rules by an example. Let the semi-span be 200 feet, the deflexion 40 feet, the length of the shortest suspending rod 2 feet, the weight of a foot in length of the roadway when loaded 5000 lbs., and the horizontal

distance D K of the point D from the center of the chain 100 feet.

Then, by the first rule given above, 2 subtracted from 40 leaves 38, which multiplied by the square of 100 equals 380,000, and this number, divided by the square of 200, gives as the quotient 9½, to which, adding 2 feet, the sum 11½ feet is the length of the suspending rod D G.

By the second rule, 2 subtracted from 40 leaves 38, twice this number, divided by the square of 200, equals ·0019, from which, subtracting ·0003, the remainder equals ·0016; then 5000, divided by this number, gives 3,125,000 lbs. for the strain upon the lowest point B of the chain; and 3,125,000, multiplied by ·0000893, equals 279 square inches for the sectional area of the chain at B.

And by the third rule, twice 9·5, divided by 100, equals ·19, the square of which, added to 1, equals 1·0261; then the square root of 1·0261 equals 1·013, which, multiplied by 3,125,000, gives 3,165,625 lbs. for the strain upon the chains at the point D; and 3,165,625, multiplied by ·0000893, gives 283 square inches for the sectional area of the chain at the point D.

MATERIALS EMPLOYED IN CONSTRUCTION.

The principal materials made use of by the Civil Engineer, for the purpose of construction, may be classified as follows:—

1. Metals.

2. Timber.

3. Natural stones.

4. Artificial stones, including bricks, and the different kinds of mortars and cements used in masonry.

Before describing the principal properties of each of these classes of materials, it will be desirable to consider briefly the subject of their strength, and to explain the circumstances which affect the same.

Strength of Materials.

The strength of materials to resist the action of any external force to which they may be exposed varies greatly with the manner in which that force is applied; and therefore it is necessary, in considering this subject, to divide the strength of materials as follows:—first, their power to resist *extension*, or the force required to *pull them asunder*; secondly, their power to rest *compression*, or the force requisite to *crush* them; thirdly, their *transverse* strength, or the force required to break a bar or beam resting at each end upon supports; and fourthly, their *elasticity*, or the force required to bend a bar or beam supported at each end.

1st.—When any material is exposed to a tensile strain, or one tending to tear it asunder, if the direction of the strain passes through the center of the piece, its strength is directly proportional to its sectional area. The weight in pounds required to tear asunder a bar one inch square of the different metals, wood, and stones, is given in the column B

in the tables of their properties given below; and the tensile strength of a piece of any other dimensions may be found by multiplying the numbers in the table by the area of the piece in square inches; thus, the weight required to pull asunder a bar of cast iron 3 inches by 4 inches would be 17,920 multiplied by 12 or 215,040 lbs.; and the weight to tear asunder a piece of white marble 1 foot square would be 551 multiplied by 144, equal to 79,344 lbs., or nearly 36 tons.

2ndly.—The experiments of Professor Hodgkinson * have shown that when a substance is submitted to a compressing force, its strength will depend upon the proportion which its height bears to its other dimensions. He found that when the height of the piece was not greater than its diameter, if round, or the length of its side, if square, its strength would *increase* as its height was diminished; but, that when the height was greater than those dimensions, fracture took place by the separation of a pyramid, cone, or wedge (depending on the form of the piece), the angle of whose side was always the same for the same material, and that the strength would not vary with an increase in the height until it became equal to four or five times the diameter, when the piece would begin to bend, and its strength would then *diminish* as its height was further increased; he also found, that within these limits the strength was proportional to the

* Experimental Researches on the Strength and other properties of Cast Iron.

sectional area. The weight in pounds required to crush cubes 1 inch square of different materials are contained in the columns A in the tables following; for any other dimensions, the numbers in the table must be multiplied by the sectional area in square inches; thus, the weight required to crush a block of Portland stone 1 foot square would be 1491 multiplied by 144, equal to 214,704 lbs., or 96 tons.*

* The following table exhibits the formulæ which Professor Hodgkinson has deduced from his experiments on the strength of columns; in which w is the weight in tons required to crush the column, d its external diameter in inches, d_1 its internal diameter (if hollow), l its length in feet, and a, b, c, and e are constants depending on the material of the column, and the values of which, for a few materials, are given in the second table below :—

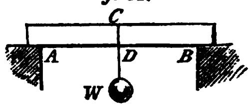
Kind of column.	With both ends *rounded*, when the height of the column is not less than 15 times its diameter.	With both ends *flat*, when the height of the column is not less than 30 times its diameter.
Solid cylindrical columns .	$w = a\frac{d^{3.6}}{l^{1.7}}$	$w = b\frac{d^{3.6}}{l^{1.7}}$
Hollow cylindrical columns	$w = c\frac{d^{3.6} - d_1^{3.6}}{l^{1.7}}$	$w = e\frac{d^{3.6} - d_1^{3.6}}{l^{1.7}}$

Material.	*a*.	*b*.	*c*.	*e*.
Cast Iron . .	14·90	44·20	13·0	44·3
Wrought Iron .	26·00	77·00	22·7	77·2
Cast Steel . .	37·50	110·90	32·7	111·1
Dantzic Oak .	1·62	4·81	......	......
Red Deal . .	1·17	3·47	......	......

When the height of the column is less than that stated in the fore-

3rdly.—Let figure 31 represent a bar or beam of any material, resting at each end on two fixed supports A and B, and having a weight W suspended from the center C.

Fig. 31.



Now the amount of W, or the weight which will be required to break the beam, when applied in the manner here described, will be directly proportional to the breadth of the beam multipled by the square of its depth C D; or, what is the same, to its sectional area at C, multiplied by its depth, and inversely proportional to the distance A B between the supports. The numbers in the column C in the tables following, show the weights in pounds required to fracture bars of the several materials 1 foot long and 1 inch both in breadth and depth, the weight being applied in the center of the bar. To find the weight in pounds required to fracture a piece of any other dimensions, we must multiply the number in the table by the square of the depth in inches, and by the breadth in inches, and we must divide the product by the distance between the supports in feet; thus, suppose the distance A B is 10 feet, the depth of the beam 6 inches, and its breadth 4

going table, it gives way partly by flexure and partly by crushing, and the column will bear a greater weight than the table would show. In this case let w be the strength calculated from the table, w_1 the strength calculated by the rule given in the text above, for the crushing strength of the material, and w_2 the actual strength of the column, then—

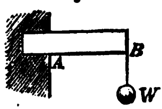
$$w_2 = \frac{w\,w_1}{w + \frac{3}{4}w_1}.$$

inches, the material being cast iron, then 2045 multiplied by 36 and by 4, and divided by 10, will give 29,448 lbs. for the weight which being applied in the center of the beam would break it.

When the weight, instead of being suspended from the center of the beam, is distributed or spread equally over it from A to B, it will support just double the load; that is, twice the weight will be required to break it when thus distributed, which would be required if suspended from the center.

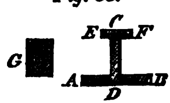
If the beam, instead of being supported at each end, is only fixed at one end A, figure 32, and has the weight suspended from the other end B, it will only bear one-fourth of the weight which it would do if supported at each end and loaded in the middle. In this case, also, if the weight be distributed equally, the beam will support twice as much as if it were suspended from the end.

Fig. 32.



In all the cases which we have considered above, the form of the cross section of the beam has been supposed to be rectangular, as in G, figure 33. This form of section, however, is not the strongest which could be chosen; for, by altering it, the same quantity of material may be made to sustain nearly three times the weight, and it is this circumstance which renders the employment of cast iron so valuable to the

Fig. 33.



engineer, who, from the facility with which it may be cast in any form, is enabled to adopt that which gives the greatest strength with the least material. A form recommended by Professor Hodgkinson, and which has been very generally adopted in practice, is shown in figure 33; the weight in pounds which would be required to be applied in the center to break a beam of this form, supported at each end, will be found by multiplying 4852 by the area in square inches of the lower flange or web A B, and by the depth C D in inches, and dividing the product by the distance between the supports in feet.

4thly.—When a beam, supported as in figure 31, has a weight suspended from its center, it is bent into a curved form, and the distance that the middle point C of the beam is drawn down below its former position, is called the *deflexion* of the beam. The amount of the deflexion is directly proportional to the weight applied, multiplied by the cube of the length A B, and is inversely proportional to the breadth of the beam multiplied by the cube of its depth; it may be determined, for any particular case, by multiplying the cube of the length in feet by the weight in pounds applied in the center, and dividing the product by the number found against the material of the beam in column D of the following tables; multiplied by the breadth and the cube of the depth, both in inches, the quotient will be the deflexion, also in inches; thus, suppose a

beam of English oak 10 feet in length, 9 inches in depth, 6 inches in breadth, and loaded with 5000 pounds in the center, what will be the deflexion? In this case, 1000 multiplied by 5000 equals 5,000,000, and 3369 multiplied by 6 and 729, equals 14,736,006; then 5,000,000 divided by 14,736,006 equals ·34 inches, the deflexion required.

General Properties of Metals.

Name of Metal.	Weight in lbs.				Strength.				
	Of a cube foot.	Of a plate 1 ft. square and 1 in. thick.	Of a bar 1 in. square and 1 ft. long.	Of a rod 1 in. in diam. and 1 ft. long.	Weight in lbs. required to crush 1 square inch.	Weight in lbs. required to tear asunder 1 square inch.	Weight in lbs. required to break a bar transversely 1 in. sq. and 1 ft. long.	Multiplier for elasticity.	Expansion in length for 1 degree of heat.
					(A)	(B)	(C)	(D)	
Cast iron	450	38·4	3·20	2·51	107,750	17,920	2045	42593	·00000617
Wrought iron..	475	40·0	3·30	2·61	....	58,952	2290	57685	·00000698
Steel	490	40·8	3·40	2·67	....	130,000	....	67129	·00000636
Copper (cast) ..	549	45·7	3·81	2·99	116,480	19,072	....	....	·00001430
Gun-metal	510	42·5	3·54	2·78	....	35,840	....	22854	·00001009
Brass (yellow)..	523	43·6	3·63	2·85	163,520	17,958	890	20671	·00001044
Lead (cast)	710	59·3	4·94	3·88	7,840	1,824	196	1667	·00001593
Zinc (cast)	439	36·6	3·05	2·40	....	....	746	31667	·00001634

Of the above metals, cast iron is by far the most extensively employed in construction. It may be divided into two varieties, the *white cast iron*, which has a white and radiated or crystalline appearance when broken, and is hard and brittle; and the *gray cast iron*, which has, when fractured, a gray colour, granular texture, and metallic lusture, and is very much softer and tougher than the white. Between these two a greât number of intermediate varieties

exist, so that we may pass from one to the other by almost imperceptible gradations. The best practical test of the quality of cast iron is by a blow with a hammer on one of its edges, which, if the iron belongs to the first variety, will break off small particles; but if to the second will only indent it. It is much used for columns, for which, from its great power of resisting compression, it is peculiarly adapted. It is also almost exclusively employed for beams or girders, although of late wrought iron has been recommended for girders, and has been successfully applied in a few cases. Wrought iron, however, is principally used for the bolts, nuts, screws, and nails, by which cast iron and timber are united, and for tie rods and stays exposed to a tensile or pulling strain. One very important purpose to which it has of late been applied is for the chains of suspension bridges.

Of the other metals, steel is very little employed in construction, being principally used in the manufacture of tools and implements. Gun-metal and brass are principally used in machinery for those parts liable to wear by friction, one of the moving parts usually being of either of these metals, and the other of cast or wrought iron. Copper, lead, and zinc are principally employed for the covering of roofs.

General Properties of Timber.

Name of Wood.	Weight in pounds. Of a cube foot.	Weight in pounds. Of a bar 1 inch square and 1 foot long.	Strength. Weight in lbs. required to crush 1 square inch.	Strength. Weight in lbs. required to tear asunder 1 square inch.	Strength. Weight in lbs. required to break a bar transversely, 1 in. sq. and 1 ft. long.	Strength. Multiplier for elasticity.	Mean diameter of the trunk.	Average length of the trunk.
			(A.)	(B.)	(C.)	(D.)	Ins.	Feet.
Ash	48	·33	...	14130	675	3807	23	38
Beech	44	·30	...	11500	519	3133	27	44
Chestnut	55	·38	...	8100	...	2140	37	44
Elm	35	·24	1284	9740	338	1620	32	44
Fir, Mar Forest	44	·30	...	6900	407	1840	...	...
„ New England	35	·24	...	10210	367	5072	...	...
„ Riga	47	·33	...	9500	369	2684	20	75
Larch	34	·24	4920	12240	330	2094	33	45
Mahogany, Honduras	35	·24	...	11475	...	3690	72	40
„ Spanish	53	·37	...	7560	...	2096		
Norway spar	36	·25	...	8320	491	3374	15	60
Oak, Adriatic	62	·43	...	12830	461	2256	...	...
„ Canadian	55	·38	...	10220	589	4863	34	53
„ Dantzic	47	·33	...	12720	486	2757	...	...
„ English	58	·41	3860	11880	557	3369	32	42
Pine, pitch	41	·29	...	9800	544	2837	...	...
„ red	41	·29	...	11840	447	4259	...	...
Sycamore	38	·26	...	9620	...	2400	29	32
Teak	47	·32	...	12920	821	5589	...	...

Of different kinds of timber, oak, chestnut (when exposed to a free circulation of air), cedar, larch, and mahogany (when kept dry), are amongst the most durable. Beech, alder, and elm, are very durable when *constantly* immersed in water or wet ground,

and are therefore well adapted for the piles, &c., for foundations. When exposed, however, to the weather, or in situations where they are alternately wet and dry, they are soon found to decay, as are also ash and mahogany. Beech, alder, and sycamore, are very liable to the attacks of worms. Oak and larch are the best woods for resisting decay when exposed to the weather; but they are both liable to split and warp in seasoning, especially oak. Mahogany warps and splits in seasoning less than any other wood. Elm and larch bear the driving of nails or bolts best, being less liable to split than any other timber.

There are two different kinds of decay to which timber is liable, namely, the *wet* and *dry rots*, both of which arise from the same origin, the fermentation and consequent putrefaction of the *alburnum* or *sap*, caused in one by alternate exposure to wet and dry, and in the other by the want of a free circulation of air round the timber. Both these kinds of decay arising from the presence of the sap, it is of importance to lessen its quantity as much as possible, with which object timber should be either felled in the winter months of December, January, and February, or if in summer, in July, at which seasons the sap exists in the tree in much smaller quantities than at others. It is also desirable, after the timber has been felled, to remove whatever sap may be in it as speedily as possible, which process is termed *seasoning* the timber, and is effected either by simply

exposing the tree, after stripping off its bark, to the air, taking care to protect it from the weather, by which the moisture and sap is gradually evaporated; or by a process termed *water seasoning*, which consists in immersing the timber for about a fortnight in a stream of pure running water, by which the sap is extracted and dissolved, and afterwards gradually drying the timber.

Various processes have been patented for preserving timber, both from rot and from the attack of worms. Of these, Kyan's consisted in immersing the timber for a period varying from seven to fourteen days (according to the size of the timber) in a solution of corrosive sublimate. By Payne's process the timber is inclosed in a close iron vessel, in which a vacuum is formed by the condensation of steam, assisted by air pumps; a solution of sulphate of iron is then admitted into the vessel, which instantly insinuates itself into all the pores of the wood, previously freed from air by the vacuum, and, after about a minute's exposure, impregnates its entire substance; the sulphate of iron is then withdrawn, and another solution of muriate of lime thrown in, which enters the substance of the wood in the same manner as the former solution, and the two salts react upon each other, and form two new combinations within the substance of the wood—muriate of iron, and sulphate of lime. One of the most valuable properties of timber thus prepared is its perfect incombustibility: when exposed to the action of flame or

strong heat, it simply smoulders and emits no flame. There are many other processes, but want of space will not allow of their being severally noticed.

General Properties of Natural Stones.

Name of the Stone.	Weight in Pounds. Of a cube foot.	Weight in Pounds. Of a cube yard.	Strength. Weight in lbs. on 1 sq. in. producing first fracture. (A.)	Strength. Weight in lbs. required to crush 1 square inch.	Strength. Weight in lbs. required to tear asunder 1 sq. in. (B.)	Strength. Weight of particles disintegrated in grains.	Bulk of water absorbed, that of the stone being 1.	Composition. Silica, per cent.	Composition. Carbonate of lime, per cent.	Composition. Carbonate of magnesia, per cent.
Sandstone	144	3888	3041	5964	772	6·2	·097	96·2	1·1	0·0
Oolite	131	3546	1491	2574	857	8·3	·155	0·4	93·8	2·7
Limestone	144	3888	1751	4068	..	10·5	·114	5·0	83·9	4·2
Magnesian limestone	141	3807	2733	5219	..	1·5	·148	1·7	54·6	40·6
White marble	169	4563	4950	6060	551	..	..	1·1	94·5	0·0
Aberdeen granite	164	4428	9251	10910	..	..	..	Quartz, Feldspar, & Mica.		
Welsh slate	172	4644	..	..	11500					

In the above table, the values are the averages of observations made, in the case of the sandstones, upon stone from the quarries of Craigleith, Darley Dale, Heddon, and Kenton; in the case of the oolites, from the quarries of Ancaster, Bath Box, Portland, and Kelton; in the case of the limestones, from the quarries of Barnack, Chilmark, and Ham Hill; and in the case of the magnesian limestones from the quarries of Bolsover, Huddlestone, Roach Abbey, and Park Nook. These observations were made by the Commission appointed to examine and report upon the best stone to be employed in the new Houses of Parliament, and on their recommenda-

tion the magnesian limestone was selected for that purpose.

The values in column A in the above table are those under which the stone first begins to crack; the next column contains the weight required absolutely to *crush* the stone: the first is that which ought to be considered, practically, as the crushing weight. The seventh column gives the weight of the stone detached by Brard's process, and may be looked upon as expressing the relative power of the weather and atmosphere upon the stone.

General Properties of Artificial Stones and Cements.

Bricks may be regarded as artificial stones, formed by moulding prepared clay into the required form and then burning the same in a kiln. The quality of bricks varies greatly according to the nature of the earth from which they are made, the care taken in their manufacture, and being more or less perfectly burnt. The weight required to *crush* a square inch of brick varies from 1200 lbs. to 4500 lbs., but about half the crushing weight will produce fracture in the brick. The weight of a cubic foot of brick-work, set in mortar, is about 117 lbs., and in cement about 125 lbs. The tensile strength of bricks is somewhere about 275 lbs. for every square inch, but in construction they are seldom, if ever, exposed to a tensile strain. Great care should be taken in the choice and selection of bricks for structures exposed to the weather or to the action of water: in such

situations, only the hardest-burnt and best-made bricks should be employed.

All kinds of mortars and cements consist of lime (a metallic oxide) combined with other substances, such as sand, gravel, clay, &c., the quality of the mortar depending upon the proportions of these ingredients, as also upon the skill with which it has been prepared. Lime is obtained by submitting limestone, which is a carbonate of lime, to a high temperature, by which the carbonic acid is driven off, and the lime left in a pure state, or only united with certain proportions of other earths and oxides. This process is termed *calcination*, and requires to be conducted with care, to ensure the whole of the carbonic acid being expelled without fusing or vitrifying the limestone. The lime, after being burnt, should not be exposed for any length of time to the air, from which it would re-absorb carbonic acid gas and water, and would be slowly reconverted into carbonate of lime. The next process is that of *slacking* the lime, which consists in pouring over it a certain quantity of water, with which it immediately combines, the water being rapidly absorbed, with the generation of considerable heat and large quantities of vapour, and the lime falling into an impalpable powder, which is a chemical compound of water and lime, termed *hydrate of lime*. The same care should be taken not to expose slacked, as unslacked, lime to the air, from which it would, in the same way, absorb carbonic acid gas.

The hydrates of lime obtained by the process above described, differ greatly in their properties, according to the composition of the limestone from which they have been obtained. The pure limestones yield a lime, termed by builders *rich* or *fat*, the principal properties of which are, that it will slack with great facility, absorb a very large quantity of water, with the generation of very great heat, and a considerable enlargement of bulk; and then, when kneaded into a paste and immersed in water, it will remain in its soft state for years, and in running water would be entirely dissolved. Those limestones, however, which contain a large quantity of silica and alumina*, yield a lime termed *hydraulic*, from its property of hardening under water; they slake with much greater difficulty than the rich limes, require less water, occupy a longer time, and do not undergo so great an increase in bulk; but their most important quality is, that when made into a paste, and immersed in water, they *set*, or become solid, in a few days, and, at the end of a year or less, attain such a degree of hardness as to splinter under a blow, and are then perfectly insoluble in water. Between these two there are a great variety of limes possessing intermediate properties. The hydraulic properties of the latter kind appear to be owing to the

* Silica is an acid formed by the union of oxygen with the metal *silicon*, and is the principal ingredient in sand. Alumina is a metallic oxide, composed of oxygen and the metal aluminum, and is the base of clays.

presence of a certain proportion of clay, and it has been found that, by mixing clay with the richer limes, and burning them together, an artificial hydraulic lime or cement may be produced, possessing the same properties; and some of these attempts have been attended with considerable success.

Mortar is prepared by kneading the lime into a paste with water, and adding certain quantities of sand, very fine gravel, or puzzuolana*, determined by the quality of the lime, and the purposes to which the mortar is to be applied.

Roman cement is a species of hydraulic lime, prepared by calcining stones or boulders of septeria, picked up on the sea-coast, principally in the neighbourhood of Harwich, and the Isle of Sheppy. The stones, when calcined, instead of being slacked, are ground in a mill to a very fine powder. This cement possesses the invaluable property of *setting* under water in a few minutes. It is frequently used quite pure, or without the admixture of any sand, in situations where rapid setting is a matter of importance.

Concrete is composed of lime, mixed with from four to seven or eight times its bulk of sand, gravel, broken stone, &c., the proportions depending upon the purpose for which it is used. It should always be thrown from a considerable height, by which its solidity is greatly increased.

* Puzzuolana is a pulverulent volcanic earth, found at Puzzuoli, near Naples, and is principally composed of silica and alumina.

DIFFERENT KINDS OF CONSTRUCTION.

Brickwork.

There are two different methods of building brickwork, depending upon the relative position in which the bricks are placed. When a brick is laid with its end appearing upon the face of the wall, as A, figure 34, it is then called a *header*, and when with its side as B, it is then called a *stretcher*. Each horizontal layer or stratum of bricks in a wall is termed a course, and it should be so built that the vertical joints between the bricks of one course are not in the same line with those of the course above or below it; thus in the figure the joint C has no joint above or below it, but solid bricks; when the bricks are so arranged, they are said to *break joint* or *bond* with each other. There are two different methods of bonding walls in very general use, namely, *old English* bond, which consists in laying a course of headers and then a course of stretchers, as in figure 34; and *Flemish* bond, which consists in laying, alternately, headers and stretchers in each course, as in figure 35. The Flemish bond has the neatest appearance upon the face of the

Fig. 34.

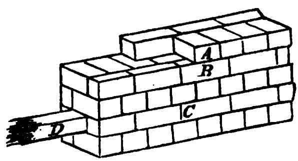
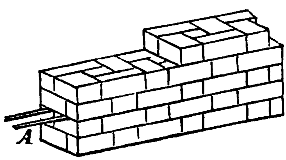


Fig. 35.



wall, but is much inferior to the old English bond in strength, and also requires much more cutting of the bricks.

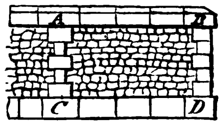
Where it is requisite that the wall should be of considerable strength, the bond of the bricks only is not always sufficient; on such occasions it was customary to build a piece of timber into the wall, as shown at D, in figure 34, which ran through its whole length. This method, however, of bonding walls is very uncertain, because the strength of the wall depends upon the timber continuing in a sound state; and should it rot, as in such a situation it is very likely to do, we have perhaps no means of ascertaining the fact, and are only made aware of it by the failure of the wall. This method of bonding is in consequence almost entirely superseded by the *hoop-iron* bond, first introduced by Sir Isambart Brunel, and which consists in laying hoop iron flatwise between the courses, as shown at A in figure 35; the iron should be slightly rusted, which greatly increases its adhesion to the cement or mortar.

Masonry.

In the construction of masonry, the same precautions are adopted as in brickwork, so to dispose the vertical joints that the wall may have a sufficient bond; and this may be easily affected, since the size of the stones is not fixed. In the neighbourhood of the quarries, where rough stone

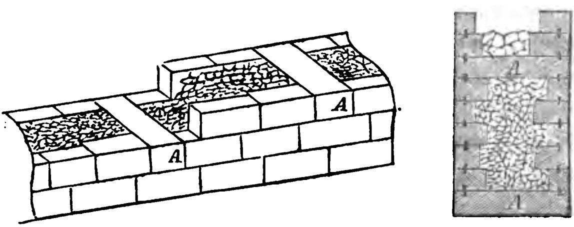
is plentiful, it is frequently employed in its rough state, without being faced or reduced to square dimensions, and is then termed *rubble* masonry. Figure 36 represents a wall built of rubble, but having the coping (A B), the plinth (C D), the quoin (B D), and the piers (A C), constructed of cut stone, which gives solidity to the wall and adds to its appearance.

Fig. 36.



When a wall of masonry is of any thickness, it is frequently cased with cut stone on both sides, the middle being filled in with rubble; in such cases, *heading* or bond stones, A A, figures 37 and 38, should be carried entirely through the thickness of the wall at certain intervals, to prevent the sides being forced apart by the settlement of the rubble between them.

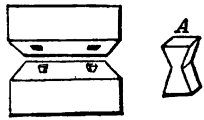
Figs. 37 & 38.



In cases where it is necessary that the stones should not slip upon each other, and also to pre-

vent the joints from separating, it is usual to insert between them a piece of iron or copper, of a dove-tail form, as shown at A, figure 39, which are termed *cramps* or *dowels;* these are inserted half in each stone; and the two having been placed, lead is run into the space round the dowel, which fixes it firmly to the stone. Dowels are sometimes made of slate or other hard stone, and are then run with cement.

Fig. 39.



Methods of Forming Foundations.

The formation of a firm and secure foundation upon which to build a structure, is frequently one of the most difficult operations which the engineer has to perform, and the method adopted must depend upon the peculiar circumstances of the case. When the natural ground is firm, and sufficient to support the weight of the structure to be placed upon it, it is only necessary to make its surface level; when, however, the original surface has a considerable slope, it will not be necessary to bring it all to one level, but it may be cut into a series of level benches or steps.

In most cases, however, the ground is not sufficiently firm to be trusted, and it is found necessary to adopt some artificial means of increasing its re-

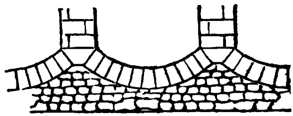
sistance. One of the most common methods of doing this, is to drive long pieces of timber, termed *piles*, vertically into the ground, until the resistance which they offer is sufficient; when they are all sawn off to the same level, and a platform of timber formed on the top of them, upon which platform the intended structure is built. The piles are usually about twelve inches square, and are pointed at their lower extremity, and shod with iron, to enable them to penetrate the ground more easily; they are driven into the ground by the repeated blows of a heavy weight allowed to fall under the influence of gravity on their upper extremity, which should be surrounded with a hoop or ring of iron, to prevent the pile being split by the blows. Fig. 40 is a section of the wall of the old docks at Hull, supported upon three rows of piles, driven three feet apart; each pile is eight inches square, and ten feet in length.

Fig. 40.

Another method is to throw the base of the structure over a large superficial area, which is sometimes done by spreading large masses of concrete over the ground, and spreading out the wall with footings, or by laying large flat stones over the ground as a foundation course upon which to commence building. When the soft ground is only superficial, and becomes firm at a greater depth, it is usual to excavate

the loose strata, and fill up to the level of the bottom of the intended masonry with concrete. When a structure is supported upon piers, or detached pillars, the bases of which do not cover a sufficient area to support them without danger of settlement, the weight which they carry may be spread over a much larger surface by turning inverted arches between them, as shown in figure 41.

Fig. 41.

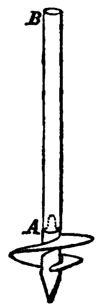


It sometimes happens, that although the ground generally may be firm, in one or two spots it may be loose or soft, and not capable of sustaining the requisite load; in such cases an arch may be turned over the soft place, if not too extensive: in cases, however, where it has been too wide to be spanned by an arch, wells of brickwork have been resorted to, which have been sunk down to the firm ground, and then the structure built upon them: this plan was resorted to by Sir Christopher Wren in building the chancel of St. Paul's Cathedral, under one corner of which a large pit, or *pot-hole*, of loose ground was found.

In conclusion, we must not omit to mention the screw-pile, invented by Mr. Alexander Mitchell, and which has been used with great success for the foundation of lighthouses, in situations where, from the

depth of water, or loose nature of the bed, any of the ordinary means would have been totally inefficient. It consists of a large spiral flange, or screw of iron, making about one turn and a half, as shown in fig. 42; it has a square spindle at A, upon which the pile or column A B is fixed; and it is secured in the ground by screwing it down to any depth that may be found requisite, which is easily effected by turning round the pile A B.

Fig. 42.

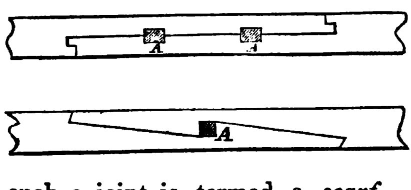


Carpentry.

The most important branch of carpentry to the Civil Engineer is that which relates to the methods of joining or connecting timbers together; and we shall briefly describe those most usually employed.

Figure 43 represents two different methods of joining two pieces of timber in the direction of their

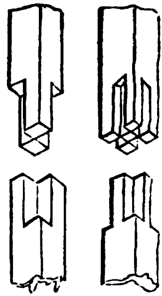
Fig. 43.



length: such a joint is termed a *scarf.* A A are wedges very slightly tapered, termed *keys;* these

keys should not be driven in tighter than is sufficient to bring the parts together, and not so as to cause any strain on the joint. It is usual, where great strength is required, to secure the joints with plates and bolts of iron.

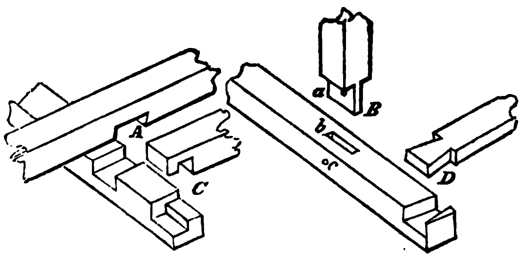
Fig. 44.



When it is desired to lengthen a timber placed vertically, as a post, it may be done in either of the ways shown in figure 44, of which the left hand figure is the simplest.

When two timbers cross each other at right angles, it is usual to notch each of them half through as at A, figure 45, which is termed *halving* them.

Fig. 45.

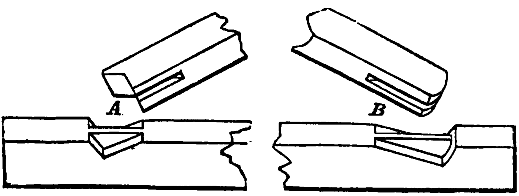


When one timber merely meets or abuts against the other, the joint is formed, as shown at B, which is termed *mortising* them together; the tongue *a* is called a *tenon*, and the hole to receive it *b* the *mortise;* the joint is usually secured by an oak

pin driven in at *c*. When both pieces meet, forming a right angle or corner, they may either be *halved* together as shown at C, or *dove-tailed* as at D; the former is the best, as being less affected by shrinkage of the wood.

When one timber abutting against another makes an acute angle with it, as in the case of the principals of a roof, the joint may be formed as shown at A, figure 46; where, however, there is a con-

Fig. 46.



siderable strain upon the joint, it is better to make it as shown at B, in which the bearing is more equal, and is not affected by any settlement of the framing.

THE END OF THE FIRST PART.

G. Woodfall and Son, Printers, Angel Court, Skinner Street, London.

THE RUDIMENTS OF CIVIL ENGINEERING.

BY HENRY LAW,

CIVIL ENGINEER.

PART II.

Special Construction.

NEW EDITION, REVISED AND CORRECTED.

LONDON:

JOHN WEALE, 59, HIGH HOLBORN.

M.DCCC.LII.

LONDON:
GEORGE WOODFALL AND SON,
ANGEL COURT, SKINNER STREET.

ADVERTISEMENT

TO THE FIRST EDITION.

It was intended to have completed the subject of Special Construction in this Second Part, but it was found impossible to do so without either treating it more briefly than would be desirable, or, on the other hand, *so far* exceeding the limits which had been assigned to the work as to oblige the necessity of raising its price. The conclusion of this subject will, therefore, be given in a Third Part, containing a detailed description with engravings of the Charing Cross Suspension Bridge, which will be followed by an article on the Construction of Tunnels, and the remainder of the Part will be devoted to the important subject of Hydraulic Engineering.

H. L.

London, 20th Feb., 1849.

In preparing a second edition of this work for press, the whole has been very carefully examined, and such errors as were found have been corrected. Some of the plates, which were worn by the large impression of the former edition, have been re-engraved

H. L.

Old Windsor, Nov. 28th, 1850.

CONTENTS OF THE SECOND PART.

CHAPTER IV.

SPECIAL CONSTRUCTION.

LIST OF ILLUSTRATIONS.

PART I.

PART II.

THE RUDIMENTS

OF

CIVIL ENGINEERING.

PART II.

CHAPTER IV.

SPECIAL CONSTRUCTION.

COMMON ROADS.

Determination of Route.

In the laying out either of a canal, common road, or railway, the first and one of the most important points to be considered is the determination of its route or general course. The selection of the best line should be guided by many circumstances, amongst which the following are the most important:—the primary object being usually the connection of two distant towns, it is desirable to obtain the most direct and shortest means of communication, which in point of distance would obviously be a straight line; but it is very seldom that a perfectly straight line can be obtained, because there are other requisites equally desirable, which can seldom be attained by taking the most direct route; these are—as little deviation in the surface of the road or canal from a perfect level as possible

(avoiding steep inclines in one case and locks in the other), economy in the construction of the line, the cost of which will be principally affected by the unevenness of the original surface of the country, the nature of the ground, and the number of streams, rivers, roads, &c., required to be crossed by bridges. There is also another circumstance which frequently makes it desirable to leave the direct and take a somewhat circuitous course, and this is the passing through or near to intermediate towns lying between the terminal ones, by which the country generally is better served, and an accession of traffic brought to the road or canal.

The course of the best line depending on so many circumstances, it will be easily understood that it requires much care and consideration on the part of the Engineer for its selection. In order to obtain the requisite data, or the information upon which to form his judgment, he usually proceeds to a general examination of the district, in which, assisted by some good map showing the physical features of the surface, and accompanied by some person conversant with the country, he ascertains the courses of the valleys and hills, makes general inquiries as to the nature of the strata, the position, population, and trade of the neighbouring towns, and all other points which may affect his selection. He then sketches out one or more lines which appear to him to be most advantageous; these he has carefully surveyed and levelled over, having also

cross levels taken by which he may be able to ascertain whether any benefit may be obtained by deviating from the line at first laid down.

Being thus in possession of all the requisite information, he finally determines the course of the line, which is then laid down upon the plan, and also marked on the ground by driving a wooden stake, about eighteen inches in length, into the ground, upon the center of the intended road or canal, at convenient distances, usually a chain (or 66 feet) apart. Very careful levels are then taken over the line thus marked out, every undulation in the surface of the ground being taken notice of; the width of every stream, river, canal, road, &c., is measured, as also the level of its surface and the exact angle (called the *angle of skew*) which its direction makes with that of the line; it is also necessary, where the surface of a road crossed by the line will require to be altered, to have levels taken along it for a short distance, so that the exact amount of such alteration may be accurately determined. From these levels a section must be formed representing upon paper the undulations of the ground; in order to render these more easily perceptible, it is usual to *distort* the section by drawing the lengths and heights to different scales. For example, suppose figure 47 to represent a section of a short line of railway. The irregular line ABCDEFGH, represents the surface of the ground; but, in order to render the undulation in

the same more distinct, the horizontal distances are drawn on a scale of 50 chains to the inch, that is, every inch measured along the line I K represents a distance of 50 chains or 3300 feet on the ground; while the vertical heights are drawn to a scale of 100 feet to the inch, that is, every inch measured in a direction perpendicular to the line I K represents a height of 100 feet. It is usual to refer the levels to some fixed point termed the *Datum*, which in the present instance is taken 45 feet below the surface of the

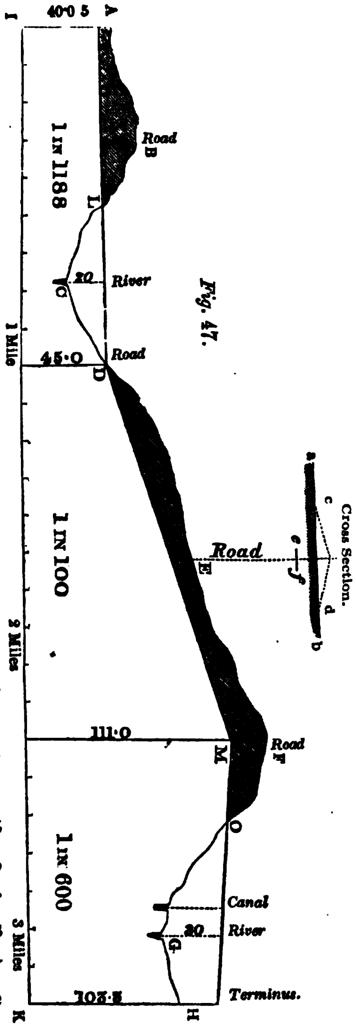


Fig. 47.

ground at the point A; a line I K, called the *datum line*, being then drawn horizontally through the datum, the heights of the ground at any point are always measured from it.

The levels having been taken and the surface of the ground *plotted* or drawn in section, the next step is to determine the levels at which the intended road or railway shall be formed; the latter being the most difficult and requiring the most consideration, will afford us the best example. Now, the principal objects to be borne in mind are—to make the surface of the railway as nearly level as possible, to make the cuttings and embankments balance each other, that is, to make, as nearly as may be, the quantity of ground excavated from the higher parts equal to that required to form the embankment across the more depressed parts, to alter and affect prejudicially the existing roads, &c., as little as practicable, and to keep the cost of the line as low as possible. In the present instance roads are crossed at B, D, E, and F, of which it is desirable that only E should be altered in level; there are also two rivers C and G, both of which require a bridge having a clear headway of at least 17 feet. Now, in order to pass under a road without raising it, the rails must be 18 feet below its surface, and, in order to leave a clear headway of 17 feet at C, the rails must be made 20 feet above that point. If, then, we draw a line A D fulfilling these conditions, it will represent the sur-

face of the rails, and the railway will be in cutting from A to L, and on an embankment from L to D. The distance AD is 90 chains, or 5940 feet, and the height of the rails at A 40 feet above the datum, and at D 45 feet above the same, being a rise of 5 feet in a distance of 5940 feet, or 1 foot in 1188, which is the inclination of the surface of the rails, and is technically termed the *gradient*. The next point requiring consideration is the road at F, in order to avoid raising which, the level of the rails must be kept as before 18 feet below its surface; then putting the point M that distance below F, and drawing the line DM, it will represent the surface of the rails, the whole distance being in cutting. The cutting at E being only 10 feet in depth, it will be necessary to raise the road at that point 8 feet, in order to obtain sufficient headway for the railway to pass under it. A cross section must be made similar to that shown in the figure, in which the *whole* line *a b* represents the original surface of the road, the *dotted* line *c d* the proposed surface of the road after being raised 8 feet, the inclination at which it is to be formed being 1 in 20, and the short *thick* line *e f* the level of the rails. The distance from D to M is 10 furlongs, or 6600 feet, and the rise of the rails 66 feet, or 1 in 100, which is the *gradient* of that portion of the railway. In arranging the level of the line from M to H, we must take care to leave a headway of 17 feet in passing over the river at G, and at first sight this might appear to be the only

circumstance to be attended to. If, however, the levels were so arranged as only to leave a headway of 17 feet at the river, the line would terminate with a descending gradient of 1 in 108, which would be very objectionable, because it is always desirable to make a railway approach the terminus on the level, or even with a rising gradient, which latter serves the double purpose of checking the speed of trains coming in, and assists in quickly getting up the speed of those going out. It will therefore be advisable to raise the line so as to lessen the rate of inclination, the doing which will be attended with very small expense, because the cutting from D to M will afford all the material required for forming the embankment. If we, therefore, increase the gradient to 1 in 600, the distance from M to H being 7 furlongs, or 4620 feet, the fall in the line will be 7·7 feet, and therefore its level at the terminus 103·3 feet above the datum; and it will be in cutting from M to O, and on embankment from O to H.

Of the Course, Gradient, and Transverse Section of the Road.

In determining the course of a road, it is frequently necessary, in order to avoid some obstacle, to change or alter its direction; in such cases, the larger and more regular the curve of the road is made the better, although with common roads it is not necessary to pay so much attention to this point as with railways, and in some instances a very sharp curve or bend may be found necessary.

In arranging the levels of a road (as also a railway or canal) it is very desirable to avoid undulations in its surface, that is, successive inclined planes alternately rising or falling, since much power is required to be expended in going up the hills, while very little will be saved in descending them. When, therefore, the two towns to be connected are nearly on the same level, we should endeavour to make the surface of the road as nearly level as possible; and, when one town stands on a higher level than the other, the connecting road should be formed as nearly as possible with a regular inclination rising from the lower to the higher. This may frequently be partially effected by making the road wind round the side of steep hills, or deep valleys, keeping in each case at the level required; it is, however, very seldom that we can entirely attain this desirable condition of the surface of the road.

When, however, undulations in the surface of the road are unavoidable, we should endeavour to make them as slight as possible, the limit (except in very urgent cases) being that inclination at which a carriage once set in motion upon the road would continue to descend by the action of gravity alone, because, if the hill is steeper than this, the carriage would have its motion accelerated in descending, and would press upon the horses, urging them forward beyond a safe speed. This limit is attained when the inclination of the road is made equal to the limiting angle of resistance for tho materials

composing its surface*, and therefore varies with the nature of the road, depending for its value upon the force required to move a given load upon it. The following Table exhibits the force required to move a load of a ton on each of the roads described, as also the limiting angle of resistance and the greatest inclination which ought to be given to the road.

Description of the Road.	Force in lbs. required to move a ton.	Limiting angle of resistance.	Greatest inclination which should be given to the road.
		° ′	
Well-laid pavement	33	0 50	1 in 68
Broken stone surface, on a bottom of rough pavement or concrete	46	1 11	1 in 49
Broken stone surface, laid on an old flint road	65	1 40	1 in 34
Gravel road	147	3 45	1 in 15

In arranging the cross section of a road, the width must depend upon the locality and the amount of traffic: for roads much frequented between large towns the width should not be less than 30 feet, with one footpath of about 6 feet in width; and, on approaching the immediate neighbourhood of the city, it may be increased to 45 or 50 feet, with two footpaths, each of 6 feet. The form of its cross section should be rounding, in order that rain falling

* The expression "limiting angle of resistance," is not used here exactly in its ordinary sense, but means the angle at which a carriage once set in motion would continue to *roll* down the incline.

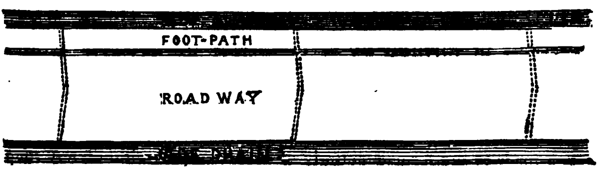
upon it may readily drain off and not remain in puddles, which would soak through and soften the foundation of the round. The form most usually adopted is that of a flat ellipse, but this is not so good as the segment of a circle, or, better still, two tangents joined by a segment, the ellipse being too flat in the center of the road and giving too great an inclination at its sides. With a width of 30 feet, the crown of the road should not be more than 6 inches above the sides, and in most cases it would be better not to make it more than 4 inches higher. The surface of roads should always be as much as possible exposed to the free action of the sun and wind, by which rain falling upon it is speedily evaporated and its surface is maintained dry; for which reason high fences or hedges by the sides of roads are objectionable, as are also trees standing by the road-side, which not only impede the sun and wind, but also injure the road by the drippings of rain falling from their leaves. Ditches should be formed on each side of the road to catch the water draining from its surface; and on the side on which is the footpath small drains should be formed under the same, to lead the water from the gutter on that side

Fig. 48.

into the ditch. Figure 48 exhibits a road 30 feet in width, with one footpath 6 feet wide, having its cross section of the form recommended above, and with side ditches.

However efficiently the surface of a road may be drained by preserving its cross section of the proper form and free from depressions and ruts, and although freely exposed to the action of the sun and wind, unless the superficial coating of the road is very compact, some portion of the rain falling upon it will soak through, and find its way to the foundation upon which the road is formed. It is therefore customary in good roads, in order to remove any water which may thus find its way to the substratum of the road, to form open tile drains across the road at certain intervals, depending upon circumstances, but usually about 60 yards apart, and having a slight inclination from the center of the road into the ditches on each side. When the road is level, these transverse drains should run straight across it at right angles to its direction; but, when it is inclined, the drains should be formed as shown on the plan, fig. 49, making an angle in the center of the road, from which point they run

Fig. 49.



straight each way into the side ditch, slightly inclined in the direction in which the road falls.

Of the different kinds of Roads, and the Materials employed in their Construction.

In the construction of any kind of road, the point requiring the first care is to form a good and sufficient foundation; by properly attending to which, although the cost of its formation may be somewhat increased, any additional outlay on that account will be more than repaid by the saving which will result in the expense of repairing the road. In the general practice, the formation of a good foundation is seldom sufficiently attended to, the principal care being usually bestowed upon the superficial coating; if, however, the foundation of the road is deficient, no care or expense bestowed upon the covering will render the road durable. It should be borne in mind that the substratum is really the working road which has to support the weight of the passing traffic, and that the office of the covering is simply to protect the actual road beneath it from wear.

Roads may be divided into two kinds, those which have their surface protected by paving, whether of stone, wood, &c., and those whose surface is formed by a covering of broken stones, or *macadamised**. The latter method derives its

* The term macadamised roads should strictly be applied only to such roads as are formed entirely of broken stones without any rough

name from the gentleman by whom they were first brought into notice.

In forming a macadamised road, if the ground is firm and dry, the only preparation required is to bring its surface to a true level; should it however be at all wet, or of a marshy character, the portion upon which the road is to be formed should be first carefully and thoroughly drained, which may usually be most effectually done by cutting deep drains running parallel to the intended course of the road on either side of it, and, if it is found necessary, forming cross drains between them having a fall each way. The ground having been thus drained, a covering of turf or of brushwood, the latter not less than 6 inches in thickness when compressed, should be laid over the surface of the soft ground, and upon this should be spread a covering of 3 or 4 inches of clean gravel, the upper surface of which should be level. The foundation of the road should now be formed, by laying a kind of rough pavement as shown in the section figure 48, consisting of rough stones of any kind of stone that can be most readily procured, laid carefully by hand with their broadest faces on the ground; these stones should be not less than 7 inches in depth in the center of the road, gradually diminishing to 3 inches in depth at the sides, and the

pavement for their foundation; but of late years it has been found convenient to apply the term to all roads composed of and repaired with broken stones.

interstices between them should be carefully filled with stone chippings, so that the upper surface when finished may form a regular curve with a convexity of about 4 inches. The material for forming the surface of the road should then be laid on, forming a uniform coat 6 inches in thickness. For the center portion of the road care should be taken to select a stone which is hard and not friable; granite, whinstone, and the harder lime stones are the best suited for this purpose; and they should be broken into angular fragments, the largest of which should be capable of being passed through a ring 2½ inches in diameter. For the sides of the road well-cleansed strong gravel may be used. A good binding of clean gravel perfectly free from earth or clay, about 2 inches in depth, should then be laid over the entire surface of the road. It is better to put only 4 inches of the broken stone at first, and, after this has become consolidated by the traffic, then to lay on the remaining 2 inches, care being taken, however, to fill up any ruts which may have been formed.

As much care and attention are required for the economical repair of roads as for their first construction. Particular care should be taken that the side ditches and drains are kept clear and free from any obstruction; ruts, hollows, and inequalities in the road should be filled up the moment they appear, the best time for doing which is after wet weather, when they are not only more readily seen,

but, the road being then soft, the new material works in without being crushed or ground to powder, for which reason the proper time for the general repair of roads is about April and October. Nothing tends more to the preservation of a road than keeping its surface clean and free from mud, which should be continually scraped off and never allowed to accumulate.

In constructing paved roads, the same care should be taken to secure a good foundation as in forming macadamised roads. The most perfect foundation for pavement is a bed of concrete, the thickness of which must depend upon the nature of the ground beneath it, but should in no case be less than 6 inches, and its upper surface should be formed with a regular convexity similar to that intended to be given to the road. Two different kinds of materials are used for paving roads, viz., stone and wood; of the former, the stone most generally employed is granite, and the best description of pavement consists of narrow stones not more than 4 inches in thickness and about 9 inches in depth placed edgewise. The stones should be beaten into their places by a heavy wooden beetle and grouted with a thin lime grouting, after which a covering of fine clean gravel, about 1½ inch in thickness, should be evenly spread over its surface. Wooden pavement has been successfully employed for several years in Russia, and has lately been introduced into Eng-

land, and is far superior to stone pavement as regards the comfort both to passengers and residents, arising from the evenness of its surface and the absence of noise; many different kinds have been tried, the objects sought for being to prevent irregular settlement of the blocks, and to remove the slipperiness of its surface; the former of these objects has not yet been, nor will it ever be, attained while the unyielding quality is sought to be obtained from the pavement itself, and so little attention is paid to the formation of a firm foundation. The timber should merely be regarded as a durable and elastic covering to protect the solid and well-formed road, which ought to be first constructed under it*.

RAILROADS.

General Arrangement of the Line, and Determination of Curves and Gradients.

The determination of the general course of a railway should depend upon the same principles as those already laid down in the case of common roads. It should, however, be borne in mind that it is a matter of much greater importance in the former than in the latter, that the line of rails should deviate as little as possible from a perfectly straight and level line. Considering a line of rail-

* For further information on this subject the reader is referred to the Rudimentary Treatise on Road-making published by Mr. Weale.

way by itself simply as a means of travelling, without considering the interest of the district through which it may pass, that line is theoretically the best which is perfectly straight and level throughout its course. In practice, however, such a line is not only unattainable, but even the attempt to approximate to it would frequently be inexpedient and prejudicial to the interests of the district passed through, on account of the large outlay which such an attempt must necessarily entail, and the obligation to construct branches to serve those towns lying to the right or to the left of the straight line, which towns a line with moderate curves might perhaps have been made to pass through.

Much difference of opinion exists amongst engineers as to the extent to which the attainment of a straight line and easy gradients should be made subservient to the peculiar requirements of the districts and to economical considerations. In a paper on the "Economy of Railways in Respect of Gradients," read by Mr. Vignoles at the tenth meeting of the British Association in 1840, he stated that, after having made a careful comparison of the working expenses of various railways in which the gradients and curves differed materially, he had arrived at the conclusion that the cost of working the line, reduced to per train per mile, might be taken on the average at 3 shillings, and that it appeared to be "*irrespective of gradients or curves.*" This is a subject not only of interest to the en-

gineer, but also to the public generally, and it would be very desirable that the results of the experience which has been gained during the eight years subsequent to the time when Mr. Vignoles made his comparison, should be collected and compared, and that the inquiry should not only include the cost, but also the average speed and number of accidents that have occurred.

Although the determination of the curves and gradients in any particular case must, in a great measure, depend upon the peculiar circumstances attending it, there are, nevertheless, certain general rules which should always, if possible, be attended to. Those relating to curves are, that sharp curves, where unavoidable, should be brought as near as possible to stations or other stopping places, and on no account on steep inclines, in order that the trains might not traverse the curve with any considerable velocity, since the tendency to leave the rails increases as the square of the speed of the train; and curves should if possible be made on those portions of the line which are either on the surface or embanked, and not in deep cutting, where the curving of the railway would prevent a clear view of the line for any distance being obtained. With regard to gradients, where practicable, they should rise each way towards a station or other stopping place, so that the gravity of the train may assist in lessening its speed when approaching the station, and in attaining speed in departing from it. In long in-

clines it is desirable to form occasionally short benches or level portions, which, while they check the speed of a descending train, materially assist those ascending.

Of Forming the Cuttings and Embankments required for Railways.

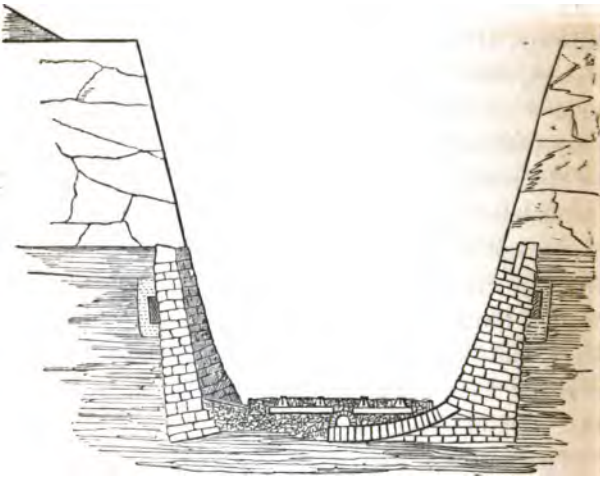
In forming the cuttings and embankments for railways, it is desirable, as far as expense is concerned, that the slopes of their sides should be formed as steep as the strata of which they are composed will allow. No general rule can be given for the slope at which the sides of either cuttings or embankments will stand, even when the description of the soil is given, because there are such a variety of other circumstances by which they are affected. Under favourable circumstances, however, in cuttings, most kinds of stone will stand vertically, chalk at about $\frac{1}{3}$ to 1*, sand and gravel at about $1\frac{1}{2}$ to 1, and clay at about 2 to 1.

The cuttings on the London and Birmingham Railway have afforded much useful information. One of the cuttings on that line, near Cow Roost, through a very wet white chalk, although only 25 feet in depth, required a slope of $1\frac{1}{2}$ to 1, while that at the north end of the Watford Tunnel, although consisting of soft wet chalk mixed with flints, stands with a slope of $\frac{1}{4}$ to 1; as does also the cutting,

* These numbers express the ratio of the base of the slope to its vertical height; thus, in a cutting 20 feet in depth, and with slopes of $1\frac{1}{2}$ to 1, the cutting would be 30 feet wider on each side at the top than at the bottom.

35 feet in depth, through chalk, chalk-marl, and gravel, at the north end of the Tring Tunnel. One of the most interesting, however, of the cuttings on this line, is that near Blisworth, a section of which is shown in fig. 50[a]. In this case, a stratum of limestone

Fig. 50[a].



rock, about 25 feet in thickness, was found about the center of the cutting (vertically), having looser strata both above and below it, and the difficulty to be over-come was to prevent the latter, consisting of wet clay, from being forced out by the weight of the superincumbent mass of rock, which was very successfully done in the following manner: a rubble wall, on an average 20 feet in height, was built on each side, underneath the rock, in the manner

shown in the figure, strengthened by buttresses at every 20 feet, resting on inverts carried under the line. Behind these walls a puddle drain was formed with a smaller drain through the wall, by means of which the water was led off from the wet strata immediately beneath the rock. The right-hand half of the section is taken through the wall, between two of the buttresses, and the left-hand half through one of the buttresses and the invert; the method here adopted is technically called *undersetting*. The rock itself is cut to a slope of ¼ to 1, and the strata above it to a slope of 2 to 1, a bench 9 feet in width being left on the upper surface of the rock.

The Newcastle and Carlisle Railway affords an example of a cutting 110 feet in depth, through clay intermixed with veins of sand, standing with a slope of 1½ to 1. This cutting is through the Cowran Hill, and the lower part, to the height of 14 feet, is supported by a stone retaining wall, having an open drain along its summit, which receives the water from the surface of the slope.

A remarkable instance of the tendency of some kinds of ground to slip has been afforded by the cutting (nearly 100 feet in depth) through the London clay on the London and Croydon Railway, near New Cross. The slopes were finished at 2 to 1, and stood (with the exception of a few small slips) at that inclination for about two years, when, after a succession of wet weather, they suddenly commenced

slipping to such an extent that the line was rendered impassable for some weeks, and some parts of the slopes had to be reduced to an inclination of 4 to 1.

Many different methods have been suggested and adopted to prevent slips from taking place. But one of the simplest means is thorough drainage, without which the best description of ground will in time be acted upon by the combined action of land springs and the weather.

With regard to embankments, although less uncertainty exists as to the slopes at which different descriptions of ground will stand, still this depends in a very great degree upon the nature of the ground supporting the base of the embankment; as well as the state of the weather, and the care and attention bestowed upon it during its formation.

Many embankments have failed in consequence of the ground upon which they have been formed not being sufficiently firm and solid to support the large additional weight thus brought upon it; to prevent this cause of failure, it is desirable to form very high embankments of the lightest material that can be obtained, to extend the base of the embankment, and, if the ground upon which it is to be formed is soft and saturated with water, thoroughly to drain it previous to forming the embankment. A remarkable instance of the failure of an embankment from this cause was afforded in the case of the Newton Green embankment, on the Sheffield and

Manchester Railway, which subsided to such an extent that the base of the embankment spread out to two or three times its original width, and it was found necessary at last to carry the rails across those parts which had slipped, upon timber shores.

A striking instance of the success of the means which we have enumerated for carrying embankments over loose ground has been afforded by the construction of the Liverpool and Manchester Railway across Chat Moss, by the late Mr. George Stephenson. In this case the ground was of so soft a nature that cattle could not walk upon it, and an iron bar sunk through it by its own weight, the moss being in many parts not less than 34 feet in depth. That portion of the moss upon which the embankment (in some parts as much as 12 feet in height) was formed was first thoroughly drained by deep drains cut parallel to the intended line of the railway; and, when this had been properly effected, the embankments were formed of the lightest material which could possibly have been employed, namely, of the dried moss itself. Had the usual heavy materials, such as clay and gravel, been employed, their weight would have caused them to sink through the moss until they reached the firm ground beneath, and the quantity which would have been required would have been immense; as was found to be the case upon the same line, where, an embankment only 4 feet in height having been formed over a

smaller moss, of a similar description, the quantity of clay and gravel employed would have formed an embankment 24 feet in height, on firm ground.

The slopes of both cuttings and embankments, as soon as they have been trimmed to their proper form, should be covered with soil, and sown with rye-grass and clover seeds mixed, which soon spring up, and form a very effectual protection from the influence of the weather.

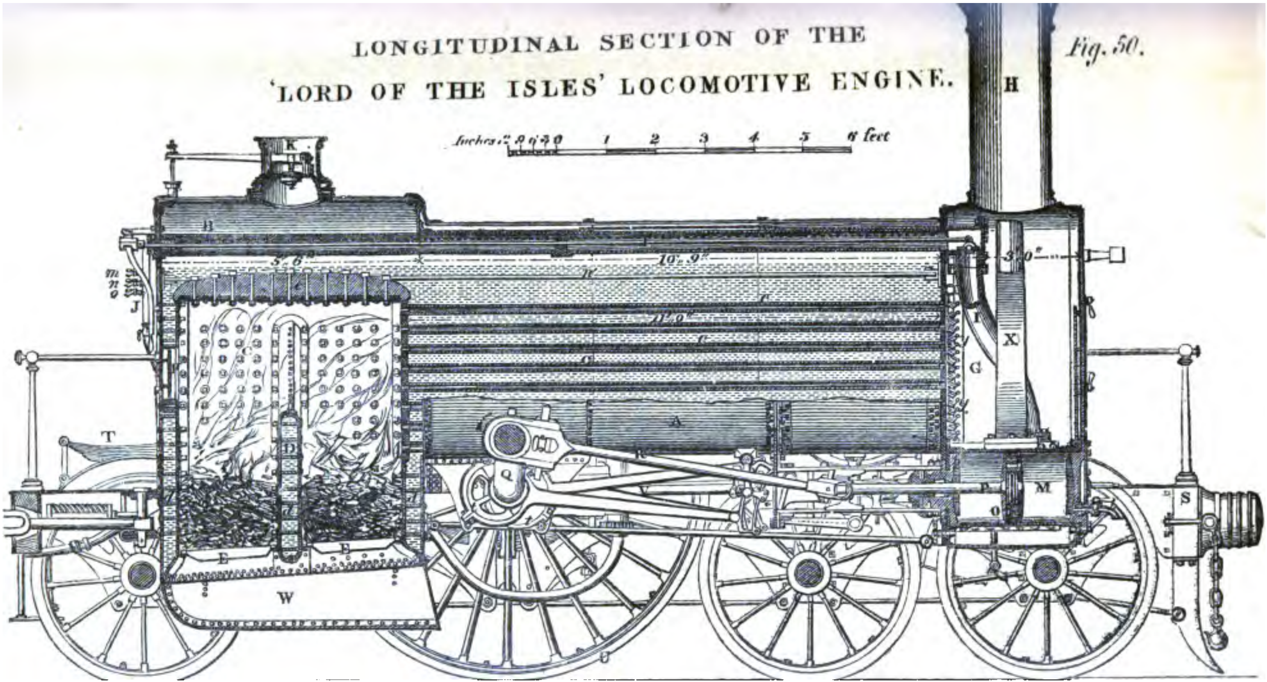
Of the different kinds of Railway.

Railways may be divided generally into *Locomotive*, *Rope*, as the London and Blackwall Railway, and *Atmospheric*, as the Kingston and Dalkey, or the South Devon Railways. Each of these might, however, be further divided into several varieties.

These different kinds of railways principally differ in the means employed for imparting motion to the trains; in the first, the train is drawn by a steam engine of peculiar construction, termed a *locomotive* engine. Fig. 50 represents a longitudinal section of the Iron Duke locomotive engine, employed on the Great Western Railway; and figures 51 and 52, two transverse sections of the same; the former taken through the fire-box, and the latter through the cylinders and chimney. The boiler A is of a cylindrical form, terminating in a square vessel B, having a semi-cylindrical shaped summit; in this latter is placed the fire-box C, the two being securely riveted

LONGITUDINAL SECTION OF THE
'LORD OF THE ISLES' LOCOMOTIVE ENGINE.

Fig. 50.



together by their lower edges, and a space of about 6 inches being left between their sides, which space is filled with water; a kind of flat tube D, termed the bridge (also containing water), runs through the center of the fire-box, and connects the two side spaces. The grate is formed by a number of wedge-shaped bars of iron E E, termed the fire-bars, which are placed with their broad sides uppermost, and their ends resting on an iron frame. The ash-pan W, below the grate, is formed of iron plates, inclosing both the sides and back; the front is, however, left open, as shown in fig. 50; and when the engine is moving forwards with a high speed, the air is driven into the mouth of the ash-pan with considerable force, and having no other means of escape passes up between the fire-bars and through the fire, causing a strong draught. A door is formed at F, through which the materials for the support of combustion are introduced, and by means of which the engine driver can from time to time examine the state of the fire. The smoke and heated air are led away to the chimney through a number of small brass tubes *c*, *c*, *c*, which pass through the center of the cylindrical part of the boiler, being surrounded on all sides by the water contained in the same, and to which they expose a very large heating surface. These tubes lead into a chamber G, the upper part of which terminates in the chimney H. The boiler is formed of wrought-iron plates riveted together, and its internal surface being exposed to a consider-

able pressure, amounting to from 60 to 100 lbs. on every square inch, it is necessary to adopt means for preventing these plates from being bent, or otherwise injured. The cylindrical portion A, from its form, is exposed to a uniform strain on every part, which the cohesive strength of the iron alone is sufficient to resist; the sides of the square portion B, however, and the fire-box C, being flat, would be forced apart by the pressure of the water between them, were it not prevented by short stays *d, d, d,* securely riveted to both plates; and the top of the fire-box, which would otherwise be forced in, is strengthened by being bolted to a number of small bridges or girders *e, e, e.* The flat ends of the boiler are secured by the fire tubes *c, c, c,* and also by bolts *n′, n′,* which pass through the boiler, and are firmly bolted at each end. To convey some idea of the amount of the pressure against the internal surface of the boiler of a locomotive engine, it is sufficient to state that, with the proportions shown in the figures, and supposing the force of the steam to be 100 lbs. on the square inch, the whole amount of this pressure would be about 3215 tons, without reckoning that upon the tubes *c, c.*

In a locomotive engine it is desirable to have as large a space above the surface of the water for steam as possible, for which purpose that part of the boiler which is above the fire-box is raised, forming the steam chamber B, as shown in fig. 50; because, when the steam space is too small, the steam passes into

TRANSVERSE SECTIONS OF THE
'LORD OF THE ISLES'
LOCOMOTIVE ENGINE.

Inches 12 9 6 3 0 1 2 3 4 5 6 Feet

Fig. 51.

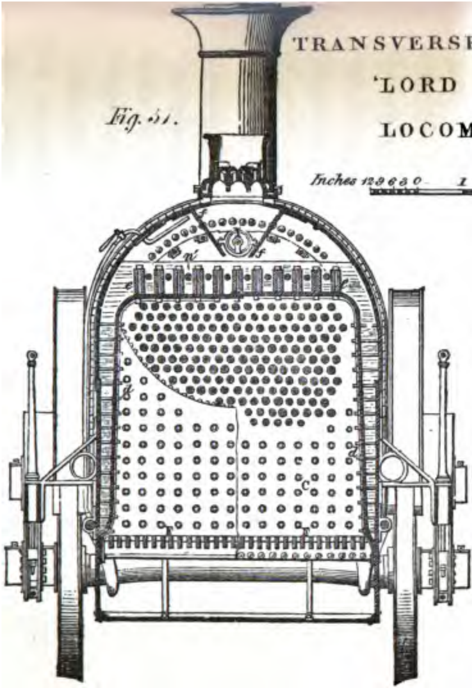
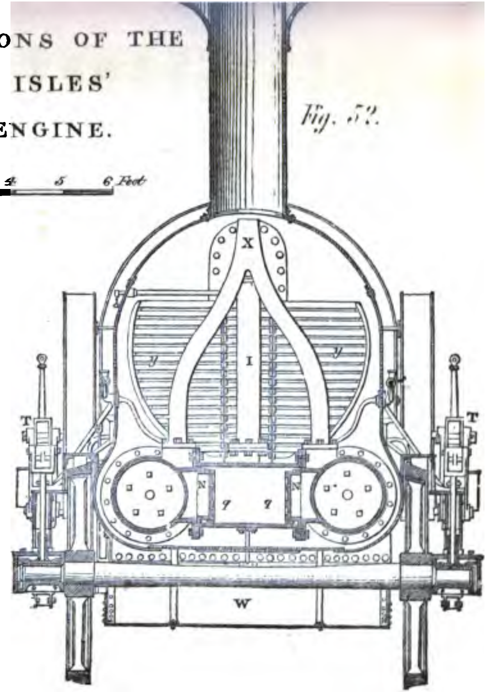


Fig. 52.



London. John Weale, High Holborn. Jan.y 1853.

the cylinders of the engine immediately as it is generated in the boiler, in which state it is mixed with a large quantity of water in a very fine state of mechanical division, which gradually accumulating in the cylinders impedes the working of the engine, and might cause a fracture of some part of the machinery. This effect, which is termed *priming*, is avoided in a degree by making the steam chamber as capacious as possible, by which means time is afforded for the separation of the water from the steam, and it is still further guarded against by the mode in which the communication is made between the boiler and the engine. The steam-pipe I, by which the steam is conveyed away from the boiler, traverses the whole length of the upper part of the boiler, and the steam is admitted through a great number of small holes in its upper side, by which it is strained, as it were, and separated from any water which might have been mixed with it; and the same object is still further effected by two plates of iron *f*, *f*, fig. 51, fixed to the upper part of the boiler, and reaching down in a sloping direction nearly to the surface of the water, leaving only a narrow space between their lower edges and the steam-pipe; so that the water which may be mingled with the steam when it is first formed strikes against the plates *f*, *f*, and falls back again into the boiler. As the water in the boiler should always be kept at such a height as to cover the top of the fire-box C, a small tube J, fig. 50, is placed vertically at the end of the boiler,

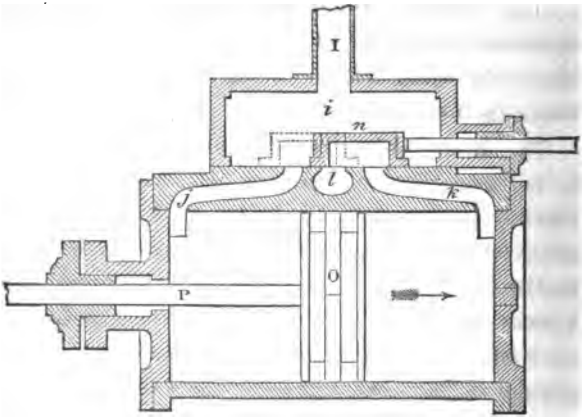
being connected with it at each extremity by a short pipe: in this tube there are three cocks *m*, *n*, *o*, placed one above the other, the heights of which are so arranged that when the water in the boiler is at its usual level, the cock *m* shall be in the steam, and the two lower ones, *n* and *o*, in the water, so that the engine driver, by simply turning the cocks in succession, and observing whether steam or water issues from them, will know the exact level of water in the boiler; for if steam issues from all the cocks, he knows that there is not sufficient water; but if water issues from all of them, he knows that there is too much. As much danger might result if the pressure of the steam in the boiler were to become much greater than that at which it was intended to be worked, two *safety* valves, as they are termed, are provided, which are so contrived that whenever the pressure inside the boiler becomes greater than it ought to be, the valves open and allow the discharge of the steam. One of these valves is placed at K on the steam chamber, and indicates, for the information of the engine driver, the pressure in the boiler at any time by a graduated scale. The other valve is usually placed on the middle of the top of the boiler, and is protected by a cover from being interfered with or altered even by the engine drivers themselves, who from habit become frequently so accustomed to danger, that, reckless of the consequences to themselves, they would not hesitate to risk their life by fastening

down the valve in order to obtain a greater speed with their engine. From the rapid motion of the engine, its external surface is constantly exposed to a fresh body of cold air, and in order to prevent the cooling influence which this would have upon the steam and water, the whole of its external surface is cased with wood, a layer of dry felt being laid between the wood and the boiler.

The steam having been generated in the boiler, is led away by the pipe I, to the cylinders M, M, where it is caused by the valves N, N, to act alternately on the top and bottom of the piston O, which fits the cylinder so tightly that no steam can pass between them, and by pressing upon it causes it to move backwards and forwards from one end of the cylinder to the other, carrying with it the piston rod P, which latter being attached to a crank Q, by means of the connecting rod R, causes it to revolve in the direction shown by the arrow. The ordinary manner in which the steam is admitted alternately to each end of the cylinder is shown in fig. 53. The steam pipe I, after leaving the boiler, divides into two branches, each of which leads into a chamber *i*, communicating with each end of the cylinder by the passages *j* and *k*, and also by means of the passage *l*, with a pipe X (figures 50 and 52), by which the steam, after being used in the cylinder, is led away to the chimney. A valve *n*, some what of the form of the letter ⋒, is so arranged that, while it forms a connecting passage between

the passage *l*, and one of the passages *j* or *k*, the other one is left open. If we now suppose the

Fig. 53.



valve to be in the position shown in figure 53, the steam from the chamber *i* would enter the cylinder by the passage *j*, and pressing upon the upper side of the piston O, would cause it to move towards the bottom of the cylinder, while the valve *n*, being connected with the machinery, would have moved in the opposite direction, and when the piston had reached the bottom of the cylinder, it would then be in such a position as to close both the passages *j* and *k*; as the machinery would, however, continue its motion from the momentum which it had acquired, it would cause the piston to begin to move back again towards the top of the cylinder, and also

move the valve *n* until it had been brought into the position shown by the dotted lines in the figure, when he passage *k* being in communication with *i*, the steam would enter the bottom of the cylinder, and now pressing on the underside of the piston, would cause it to continue its motion; while the steam which had previously occupied the upper part of the cylinder would escape by the passages *j* and *l* into the pipe X, from which, being expelled with some violence into the chimney, a powerful and continuous draught would be produced through the fire. The cylinders being inclosed in the chamber G are always surrounded with heated air, by which means any condensation of steam in them is prevented.

The form of valve *n*, which we have just described, is open to the objection that the steam pressing with considerable force on its upper surface, causes great friction, from which results the double disadvantage of rapid wear of the face of the valve, and the requirement of a considerable force to move the valve. In the 'Iron Duke' these objections are removed by connecting each valve with a piston *q*, fig. 52, fitting exactly the steam-tight cylinder *r*, situated within the chamber *i*, into which the steam is conveyed in the manner already described from the boiler by the pipe I, which does not, however, divide into two branches in this case, as one steam chamber, *i*, is made to serve for both cylinders. Now the chamber *i* being always filled with steam, and the steam being prevented from

entering into the space shown between the pistons *q*, *q*, their outer surfaces will be subjected to the same pressure as the valve N, and these two pressures being in opposite directions will neutralize each other, and relieve the face of the valves from the excessive pressure to which by the ordinary arrangement they are subjected. The valves N, N, are opened and closed at the proper intervals by means of eccentrics *t*, *t*, in the usual manner*.

It has been mentioned above, that a powerful draught is caused through the furnace and fire tubes *c*, *c*, by the peculiar form of the ash-pan W, by which the air is forced or blown through the fire; and also by allowing the waste steam from the cylinders to escape into the chimney H, by means of the pipe X, the effect of which is to produce a partial vacuum in the upper part of the chimney, in consequence of the air being thus forcibly driven out of it by the almost constant blast from the pipe X. This vacuum causes the external air to rush in through the grate and fire with a very high velocity, and produces a rapid combustion and intense heat. It is, however, sometimes desirable to lessen the draught, and this is effected by a peculiar contrivance, which consists of a kind of iron Venetian blind placed in the smoke-box G, immediately in front of the fire tubes *c*, *c*, as shown at *y*, *y*, in figs. 50 and 52. It is composed of a number of narrow plates of iron, connected to a frame of iron

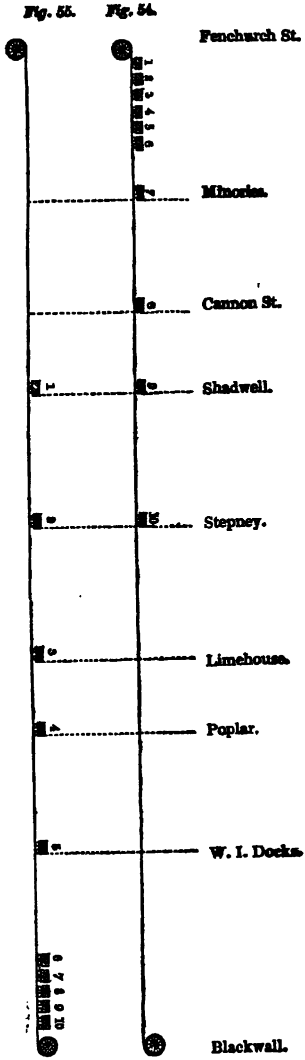
* See Rudimentary Treatise on the Steam Engine, page 45.

by hinges, in such a manner that, by raising the frame by means of a lever worked by a handle outside the smoke-box, the plates are all set edgeways, so as to offer scarcely any obstacle to the free passage of air out of the tubes *c*, *c*; but when it is desired to damp the fire, by simply depressing this frame, the plates are caused to close upon each other, similar to a Venetian blind, when the laths are placed so as to exclude as much light as possible.

The boiler and machinery are firmly connected, by means of iron brackets, with a strong rectangular framing of timber and iron S S, which is supported through the intervention of the springs T T by 8 wheels, one pair of which, U U, is firmly fixed upon the axle having the cranks Q Q, and are therefore caused to revolve with them when the engine is set in motion. By the friction of the wheels U U upon the rails when they are made to revolve, the engine is caused to move forward, drawing with it any carriages, &c., to which it may be attached. The engine is always followed by a carriage called the *tender*, which contains coke and water, for the supply of the furnace and boiler: the water is pumped into the boiler from the tender by two small force pumps V V.

We next proceed to describe the method of traction employed upon the London and Blackwall Railway, where the carriages are drawn by a rope moved backwards and forwards along the line by stationary engines at each end. Fig. 54 is a gene-

ral section of this line, showing the position of the several intermediate stations, of which there are no fewer than seven: four of these, namely, The Minories, Cannon Street Road, Shadwell, and Stepney, communicate with the Blackwall Terminus; and five, namely, Shadwell, Stepney, Limehouse, Poplar, and the West India Docks, with the London Terminus.



At each end of the line, a pair of powerful marine engines is erected, to which the drums for winding up the rope are connected by friction clutches. These drums are of cast iron, each 23 feet in

diameter, and their circumference revolves, on the average, at the rate of 26 miles per hour. The rope is 5¾ inches in circumference, and, being upwards of 6 miles in length, weighs about 40 tons; it is sufficiently long to reach from one end of the line to the other when somewhat more than half the rope is wound upon one of the drums. It is supported along the line by cast-iron wheels, termed *sheeves*, 3 feet in diameter, and 7½ inches in width, which not only prevent the rope from trailing upon the ground, but also guide it round the curved portions of the line. The carriages are connected to the rope in such a manner that they can be instantly released without stopping the motion of the rope, and again connected if required.

In order to understand the system of working the line, we must refer to the sections, figures 54 and 55, the former of which represents the position of the carriages upon the line ready for a down journey. It will be seen that there are six carriages at the Fenchurch Street terminus, of which No. 1 is to be left at the Shadwell station, No. 2 at Stepney, No. 3 at Limehouse, No. 4 at Poplar, No. 5 at the West India Docks, and No. 6 at Blackwall. The carriages numbered 7, 8, 9, and 10, standing at the Minories, Cannon Street, Shadwell, and Stepney, are to convey the traffic from those several stations to Blackwall. If we now suppose half the rope to be wound round the drum at the London end, and the other half extending along the line and attached

to the drum at the Blackwall terminus, and each of the carriages separately connected with the rope, upon a signal being sent by means of the Electric telegraph from each station to Blackwall that all is ready, the engine there will be started and the rope will be wound upon the drum at that end with a velocity of about 26 miles an hour, all the carriages attached to it being drawn along at the same speed. Now the carriage No. 10, from Stepney, will be the first to arrive at Blackwall, and as soon as it approaches within a short distance of the terminus it is released from the rope and runs by its own momentum into the station, being properly brought to rest by the breaksman, one of whom is attached to each carriage. The next in order of arrival is No. 9 from Shadwell, then No. 8 from Cannon Street, then No. 7 from the Minories, and, lastly, No. 6 from Fenchurch Street, each of which, as they approach the Blackwall terminus, is released from the rope, and runs separately into the station. Of the six carriages which leave Fenchurch Street, only one reaches Blackwall: they all proceed together until they nearly approach the Shadwell station, when the hindmost carriage No. 1 is released from the rope, and by means of its breaks brought to rest at the station, while the remaining five carriages proceed on their journey with undiminished speed; and in a similar manner one of the other four carriages is successively left at the Stepney, Limehouse, Poplar, and West India Dock stations, as the

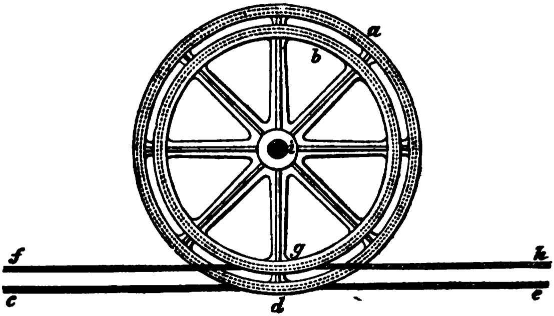
train passes, only the first carriage ultimately reaching Blackwall. As soon as the last carriage has been released from the rope, the engine at Blackwall is stopped, and the rope brought to a state of rest.

Figure 55 represents the position of the several carriages on the line upon the conclusion of the down journey which we have just described. The carriages having been again connected with the rope, and the signal given that all is ready, the engines at the London end are set to work, and the rope being drawn back again to its former position, each of the carriages is again brought back to the station from which it originally started, when they again assume the positions shown in fig. 54, and are ready to start for another down journey.

It will easily be understood, that considerable power must be expended in drawing the rope, which we have already stated weighs about 40 tons, at so high a speed, backwards and forwards each journey. In order to obviate this objection, a very ingenious modification of the rope railway has been suggested by Mr. Elijah Galloway, the principle of which is exemplified in fig. 56. Let *i* be one of the axles of the foremost carriage, having two grooved wheels, of different diameters; one *a*, say 4 feet, and the other *b*, say 3 feet 6 inches in diameter, and both firmly fixed on to the axle *i*. Then, let us suppose two separate ropes, both extending the whole length of the line, one, *c d e*, passing round the wheel *a*, and the other, *f g h*, round the wheel *b*. Now it is evident,

if the end *c* of the first rope be held fast, and a moving force be applied to the end *h* of the

Fig. 56.



other rope drawing it in the direction *g h*, that the axle *i* will be caused to revolve, and that the carriage to which it is attached will be drawn along with a velocity as much greater than that of the rope *f g h*, as the distance *i d* exceeds the distance *d g*, or with eight times the speed of the rope. For if we consider the spoke *i d* as a lever turning on the point *d* as a fulcrum, and the rope *f g h* as attached to it at the point *g*, then it is evident, if the distance *d i* is eight times *d g*, that for every inch that the rope *f g h* is drawn, the axle *i* will be made to move in the same direction 8 inches.

If, therefore, stationary engines were fixed at certain intervals along the line, and the rope *f g h* being wound up by them were made to move with a velocity of say 5 miles per hour, the train to which it was connected, in the manner which we have just

described, would be carried along at the rate of 40 miles per hour; and the power expended in moving the rope would be less than an eighth of that which would have been lost in working upon the ordinary system.

The last kind of railway which we have to describe is the *atmospheric*, which is so called in consequence of the motive power being derived from the pressure of the atmosphere. It has been explained at page 14 of Rudimentary Pneumatics, that the air which surrounds us not only has a considerable weight, but that, owing to a peculiar property belonging to all elastic fluids, the pressure resulting from the weight of the superincumbent air not only acts downwards, but in every other direction, either to the right, to the left, or even upwards. On the atmospheric railway this property of the air is made available for the purposes of locomotion, in the following manner:—an iron tube about 18 inches in diameter (the size, however, depending on the amount and description of the traffic), is laid along the center of the railway, between the two rails, extending the whole length of the line. In this tube a piston is inserted, which fits the sides of the same with sufficient accuracy to prevent the escape of any air between them; now, if we suppose this piston to be at one end of the tube, the other end being closed, in the ordinary state of things, although the weight of the external atmosphere amounting to 14·75 lbs. on the square inch, or

3753 lbs. over its whole area, would be borne by the outer side of the piston, a similar and equal pressure is produced against its inner surface by the effort of the air inclosed within the tube to escape, and which, having been, previous to the closing of the tube, exposed to the weight of the external atmosphere, had been compressed until its elastic force had become sufficient to sustain the same, and from which, being now relieved by the intervention of the tube, it exerts a force in its efforts to escape exactly equal to the weight of the external air. If, however, we by some means withdraw a portion of the air from within the tube, its elastic force will be reduced, and the pressures on the two sides of the piston will no longer be equal; and when the difference of those pressures has become sufficient to overcome the friction of the piston, it will begin to move towards the closed end of the tube, and will continue its motion throughout the entire length of the same, provided that the air is continually withdrawn from the tube, so as to keep up the requisite difference of pressure on the two surfaces of the piston; and if, when the piston has thus arrived at the closed end of the tube, the order of things be reversed, and that end being now opened the other be closed, and from it the air be now withdrawn precisely in the same manner as was previously done at the other end; the piston, being pressed upon in an opposite direction, will commence moving back again through the tube, and will be brought back to the

Fig. 3.

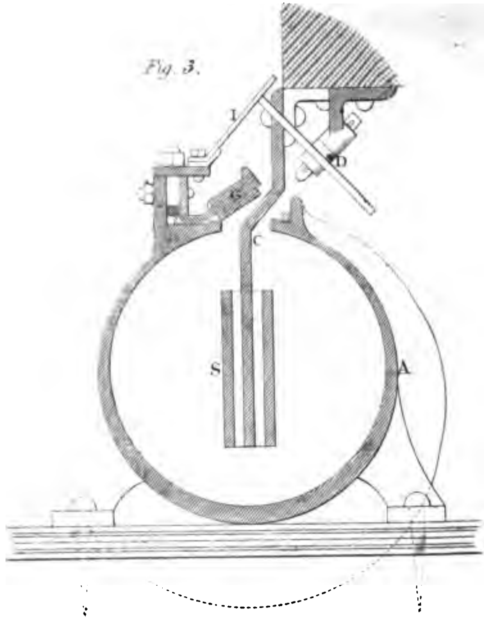


Fig. 2.

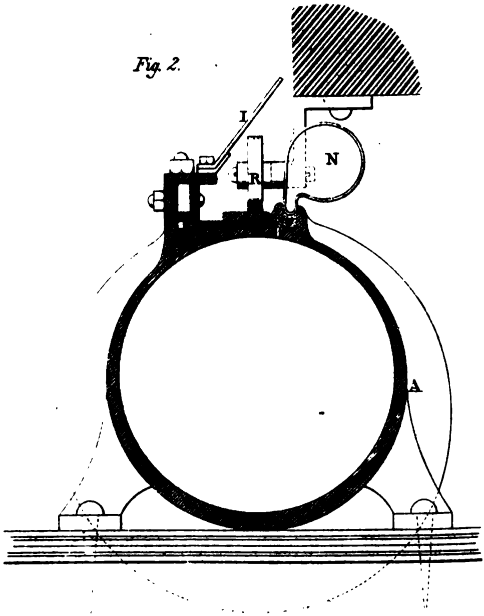
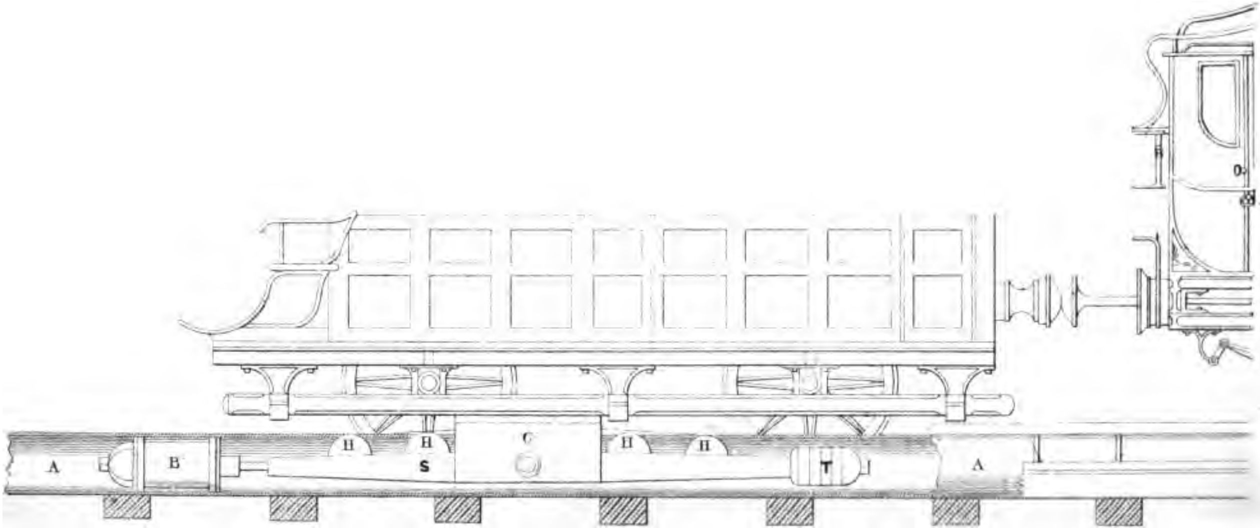


Plate 1.



position from which it first started. We have, however, yet to explain how the piston within the tube is so connected with the carriages upon the line of rails as to impart its motion to them, and cause them to traverse with it the line, alternately from one end to the other; and it is in the varying method of effecting this, that the principal differences exist between the several atmospheric systems that have from time to time been patented. That, however, which we are about to describe, was originally patented by Messrs. Clegg and Samuda, and is the only one which has as yet been adopted in practice. In plate 1, fig. 1, is an elevation of a carriage on the railway, a portion of the tube being put in section for the purpose of showing the piston within it; and figs. 2 and 3, in plate 2, are transverse sections of the tube on an enlarged scale. A A is the tube of cast iron securely fixed to the same sleepers as those which carry the rails; B is the piston, to which is attached the long bar S, having a weight at its other end, T, to balance the weight of the piston, and being attached to the first carriage by a flat bar or plate of wrought iron C, termed the *coulter*, and which passes through an opening in the upper part of the tube, as shown in fig. 3. This opening or slit extends throughout the whole length of the tube, and is covered by a valve of leather G, shown on a larger scale in figs. 2 and 3, strengthened by plates of iron riveted on its upper and lower sides; this valve of leather being securely bolted to the tube, along only

one edge, the other may be raised or lowered at pleasure, turning about the fixed edge after the manner of a hinge. The iron plate on the upper side of this valve is somewhat wider than the opening in the tube, for the purpose of preventing its being forced into the tube by the pressure of the air; and the lower plate is made exactly to fit the same, so as to form an entire circle, and prevent any escape of air round the piston. The sides of the opening in the tube upon which the leather bears, are planed perfectly flat, and still further to ensure the closing of the valve being air-tight, a composition formed of bees'-wax and tallow is run in at F, fig. 2, between the valve and the tube; this composition, although solid at the ordinary temperature of the atmosphere, is readily melted by a slight additional heat, and then, attaching itself both to the leather and the metal, forms, as it were, a hermetical sealing to the joint, and renders it almost entirely impervious to the air. This valve is protected from external injury and from the weather by thin plates of iron, I, about 5 feet in length, and attached to the tube by a leathern hinge. In its ordinary state, when no train is passing, this valve is closed, as shown in fig. 2; but in order that the coulter C may readily pass along the opening in the tube, four wheels, H H H, are attached to the bar S within the tube, which raise or open the valve, as seen in figs. 1 and 3, leaving sufficient space for the coulter to pass without touching either the side of the opening or

the valve. After the coulter has passed, the valve is again pressed down into its place by a wheel R, fig. 2, attached to the back part of the first carriage, and is immediately followed by a heater N, fig. 2, which melts the composition F, and again hermetically closes the joint which had been momentarily broken for the passage of the coulter C. Hitherto, in practice, the exhaustion of the air from the tube has been effected by air-pumps, worked by stationary engines placed at intervals of from 3 to 5 miles apart, although other means are available and have been suggested for the purpose, such as producing the exhaustion by the condensation of steam, or by filling a vessel with water and allowing it to escape by a descending pipe upwards of 32 feet in height.

We have previously stated that the total pressure of the air resulting from its weight is on the average about 14·75 lbs. on the square inch; but this is upon the supposition that a perfect vacuum is obtained in the tube, or that the *whole* of the air has been extracted from the same: this, however, it would not only be impossible to perform, but inexpedient to attempt, because the power required to extract a given weight of air increases as the quantity in the tube is diminished, and that in such a ratio, that to produce twice the degree of rarefaction would require the exertion of four times the power; added to which, any air which by leakage might find its way into the tube, would expand and occupy a portion of

the tube directly proportional to the degree of rarefaction which had been obtained; for these reasons it has been proposed only to employ half a vacuum, that is, only to withdraw half the air from the tube, by which a pressure of about 8 lbs. on every square inch of the piston would be obtained; and, supposing its diameter to be 18 inches, this would amount to 2116 lbs. over its whole surface, and would be capable of drawing a train weighing about 55 tons on a level line at a speed of 30 miles per hour; or one of about 35 tons at the same speed up an incline of 1 in 100.

A new atmospheric system has lately been proposed by Mr. J. B. Piatti, of Milan, and patented in this country by Messrs. Prosser and Carcano, in which it is proposed, instead of exhausting the air from the tube, and employing the atmospheric pressure as the motive power, to force air into the tube, and propel the carriages by the elastic force of the air thus compressed behind the piston. In this system the longitudinal valve is proposed to be constructed on a similar plan to that of Clegg and Samuda's, with some slight modifications in consequence of its opening inwards instead of outwards.

Having described each of the three means which have hitherto been employed for the purposes of traction on railways, we will proceed briefly to notice the several advantages and disadvantages peculiar to each system. One of the principal advantages urged in favour of the atmospheric system by its sup-

porters, is that of saving the weight of the locomotive engine and its tender, amounting to from 15 to 30 tons, or upon the average about 20 per cent. of the whole weight of the train; and it is considered that the advantage would not be confined to the mere saving of weight, but that, if the locomotive engine were dispensed with, the derangement of the rails, &c., from the passing traffic being in a great degree caused by the peculiar action of the locomotive in dragging by the rails themselves, would be considerably lessened. Steeper gradients might also be employed on lines worked by the atmospheric or rope systems than by the locomotive, since the latter are limited by the adhesion of the driving wheels to the rails, and on the former the motive power might readily be varied to suit the varying resistance occasioned by any alteration in the gradients of the line. The atmospheric and rope systems possess the further advantage of being much less liable to accidents from collision, and entirely free from the possibility of the train or neighbouring property being set on fire, a casualty which has on one or two occasions occurred on locomotive lines. On the atmospheric, also, the chance of being thrown off the line is much lessened, in consequence of the leading carriage being attached to the pipe. The advantages possessed by the locomotive over the other systems are, that the person in charge of the train has more perfect control over the motive power, that the locomotives are very useful for moving the

carriages about at the stations, and that the traffic of the line is not so likely to be interrupted on the locomotive as on the other lines, since nothing but a derangement of the rails themselves could produce a stoppage upon the former, while any casualty occurring to the machinery or to the tube in the latter system, would interrupt the traffic over that section of the line upon which the derangement had occurred.

While the rope system possesses many of the advantages in common with the atmospheric over the locomotive, it has the disadvantage of the weight of the rope to be moved with the train, although this objection would be somewhat reduced by the adoption of Mr. Galloway's plan, in which the velocity of the rope would not be more than about an eighth of that of the train, and the whole length of the rope would be materially reduced.

With regard to the expense of working, it has been asserted that the cost would be much smaller with stationary than with locomotive engines, the repairs required by the former being small in comparison with those of the latter, while the number of engine drivers would be fewer, and the fuel consumed cheaper and less in quantity; at the same time, in many situations auxiliary power might occasionally be obtained from natural sources, such as the wind, or streams of water.

Of Forming the Roadway or Permanent Way.

We come now to describe the manner in which the *Permanent Way* (as it is technically called) is formed; that is, the rails by which the carriages are guided and prevented from deviating from the line of the railway; and in doing so we must not omit to notice the *tramplates* which were at first adopted, and which have now universally been superseded by the *edge rail.*

The essential difference between a railway and a common road consists in forming a smooth narrow surface for tho wheels of the vehicles to run upon, with the means of preventing them from deviating from the track thus formed. Two different modes of effecting this have been adopted, which are shown in figures 57 and 58. By the first method (figure 57, the path for the wheels is formed by iron plates, and they are prevented from running off these plates by a flange *a*, formed on their outer edge; these are termed *tramplates*, and a road so formed is called a *tramway;* this method has, however, been generally superseded by that shown in figure 58, where the track for the wheels is formed by a narrow bar of iron, placed edgewise, in consequence of

Fig. 57.

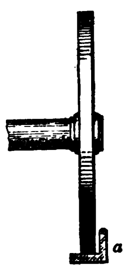
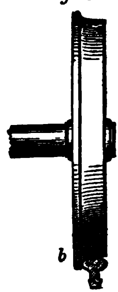


Fig. 58.



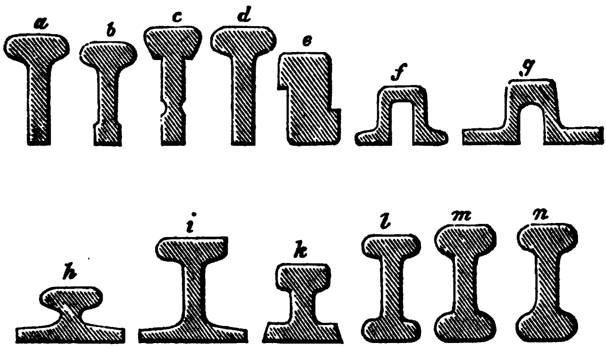
which it is termed the *edge rail*, and the road formed with them a *railway;* in this case the flange *b* for guiding the wheel is placed upon the wheel itself instead of on the rail. In comparing the two methods, it will soon be seen that the railway possesses many advantages over the tramway. In the latter, the wheels are only prevented from running off the tramplates by coming into contact with one or other of the flanges on their edges, while in the former a very simple and beautiful means (which we shall describe presently) has been devised by which the wheels are preserved in thêir proper position on the rails without their flanges coming in contact with the rails at all; a circumstance which only occurs when any unusual force solicits the carriage to deviate from its proper course. The effect of the wheels thus coming into contact with the edges of the trams is to cause a great additional resistance to the motion of the carriages, and consequently a large additional cost in overcoming it. Another disadvantage is, that the angle of the tramplate formed by the raised flange is very likely to become filled with rubbish, by which the friction of the wheels is still further increased.

A great many different forms of rails have been adopted, a few of which are shown in figure 59; the names of the railways on which they have been employed, their weight in pounds for every yard in length, and the distances apart at which they are supported, being shown in the following table.

Reference to Fig. 59.	Name of Railway.	Distance of chairs apart.	Weight in lbs. of 1 yard in length of the rail.
		ft. ins.	
a	Durham and Sunderland . .	3 0	42
b	Berlin and Potsdam	...	52
c	London and Blackwall . . .	...	56
d	Manchester and Birmingham .	...	65
e	Saint-Etienne to Lyon (New).	3 6	50
f	Wilmington and Susquehanna.	...	40
g	Great Western	Continuous Bearing.	44 to 62
h	London and Croydon . . .	Id.	55
i	Morris and Prevost	...	56
k	Birmingham and Gloucester .	2 6	56
l	London and Birmingham . .	3 9 to 4 0	65 to 75
m	London and Brighton . . .	3 9	76
n	Midland Counties	5 0	77

It should be stated that the upper surface of each of the rails shown in the figure is made slightly

Fig. 59.



rounding, the object of which we have now to explain. On a common road or on a tramway the

wheels are *cylindrical*, that is, the diameter of the wheel is the same both on its inner and outer sides, as shown in figure 57; but upon a railway the wheels are made slightly *conical*, as shown in figure 60, so that the diameter (A B or C D) of the wheel on its outer side is about half an inch less than its diameter (E F or G H) on its inner side near the flange. Now the effect of this difference in the inner and outer diameters of the wheel is to keep the carriage in its proper position in the center of the railway, and to prevent the flanges of the wheels from coming into contact with the rails unless under extraordinary circumstances, such as a very strong side wind, or a sharp curve. In figure 61, the wheels of the carriage are represented as being thrown over on one side, so that the flange of the right-hand wheel has been brought nearly to touch the rail; now if the wheels were cylindrical, and the force which had caused the carriage to swerve in the manner shown in the figure were still to continue in action, the flange would be brought into actual contact with the rail, and would so remain

Fig. 60.

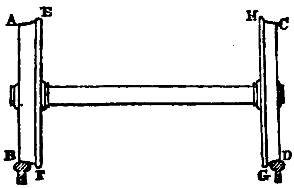
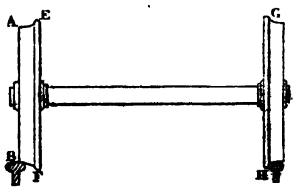


Fig. 61.

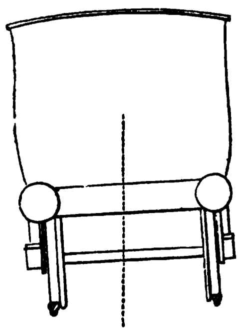


until the force ceased, or until some greater force solicited the carriage to swerve in the opposite direction; but if we carefully examine the diagram, we shall perceive that the deviation of the carriage to the right has brought the outer and smaller diameter of the wheel A B to bear upon the left hand rail, while the inner and larger diameter of the wheel G H is brought to bear upon the right-hand rail, for in consequence of the upper surface of the rail being slightly rounding, the wheel only rests upon it in one point. With a displacement equal to that shown in the figure, the difference of the diameters of the wheels would be about three-quarters of an inch, which would cause a difference in their circumferences of upwards of two inches; and as the distance that each wheel would advance upon the rail in one revolution would be equal to its circumference, and the two wheels being firmly fixed on to the same axle are obliged to revolve together, it follows that, for every revolution that they make, the right-hand wheel will advance two inches more than the left-hand, and quickly restore the carriage to the position shown in figure 60, where the diameters of the wheels being the same, the carriage has no tendency to move towards either side.

This self-adjusting action of the conical wheels is found sufficient to preserve the carriages in their proper position upon the rails on those portions of the line which are rectilinear or straight; but on

the curved portions a new force, the centrifugal force, is called into play, by which the carriage is solicited to move in a straight line; and if the radius of the curve is less than a certain limit, the mere action of the conical wheels is not sufficient to counteract this tendency of the carriages to move in a straight direction, and to cause them to follow the course of the required curve. To effect this, therefore, and prevent as much as possible contact between the flanges of the wheels and the rail, another means has been devised of throwing the carriages over to the opposite side to that on which the centrifugal force tends to keep them. This means consists in raising the rail on the outer side of the curve to a certain height above that on the inner side, by which the carriage is thrown over into the position shown in figure 62, and a tendency given to it to slide towards the inner side; the height, or, as it is termed, the *superelevation*, of the outer rail being so adjusted that this tendency, combined with the effect of the conical wheels, is just sufficient to balance the centrifugal force.

Fig. 62.



This raising of the outer rail is, however, only requisite when the radius of the curve is less than a

certain limit, which limit may be found by the following rule:—

To ascertain the least radius which can be employed without raising the outer rail.—Divide the breadth of the tire of the wheel (A E, figure 60) by the difference of the diameters of the inner and outer sides of the tire (A B and E F); multiply the quotient by the diameter of the wheel (A B) and by the distance between the two rails (F G), and divide the product by twice the space allowed *on each side* between the rails and the flanges of the wheels (all the dimensions being taken in feet); and the quotient will be the smallest radius in feet which may be used without raising the outer rail.

For example, what would be the least radius which could be employed without raising the outer rail, on a narrow-gauge line, the distance between the rails being 4·7 feet, the diameter of the wheels 3 feet, the breadth of their tires ·3 feet, the difference of the two diameters ·06 feet, and the play allowed upon each side between the flanges and the rails ·025 feet?

Now ·3, divided by ·06, equals 5, which, multiplied by 3 and by 4·7, equals 70·5, and this divided by twice ·025 would be 1410 feet, the least radius required. In the case of a broad-gauge line, if the rails are 7 feet apart, and the wheels 4 feet in diameter, the other dimensions remaining as before, then the least radius will be 2800 feet.

When, however, the line curves with a less radius than that given by the rule, it becomes necessary to

raise the outer rail to a certain extent, which depends upon the radius of the curve and the speed of the train, and may be determined by the following rule:—

To ascertain the height that the outer rail should be raised.—Subtract the radius of the curve from the least radius found by the preceding rule, and divide the remainder by the radius of the curve and by the least radius; multiply the quotient by the width between the rails, by the square of the velocity of the train in miles per hour, and by ·782; and the product will be the height in inches that the outer rail should be raised.

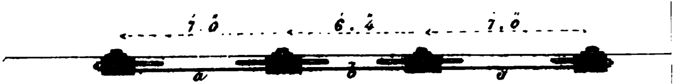
As an example of the application of the rule, the following table has been computed, showing the heights which the outer rail should be raised, both on the broad and narrow gauges, for curves of different radii, and with trains travelling at different speeds, the several dimensions being taken the same as in the foregoing example.

Radius of the Curve.	BROAD GAUGE. Velocity of the train in miles per hour.			NARROW GAUGE. Velocity of the train in miles per hour.		
	15	30	60	15	30	60
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
5 chains = 330 ft.	——	——	——	1·92	7·67	——
10 „ = 660 „	1·43	5·71	——	·67	2·67	10·68
15 „ = 990 „	·80	3·22	12·86	·25	1·00	4·00
20 „ = 1320 „	·49	1·97	7·88	·04	·16	·64
25 „ = 1650 „	·31	1·23	4·90	——	——	——
30 „ = 1980 „	·18	·73	2·92	——	——	——
35 „ = 2310 „	·09	·37	1·49	——	——	——
40 „ = 2640 „	·03	·11	·44	——	——	

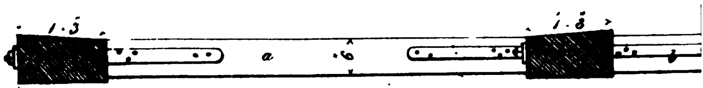
GREAT WESTERN RAILWAY.

Fig. 63.

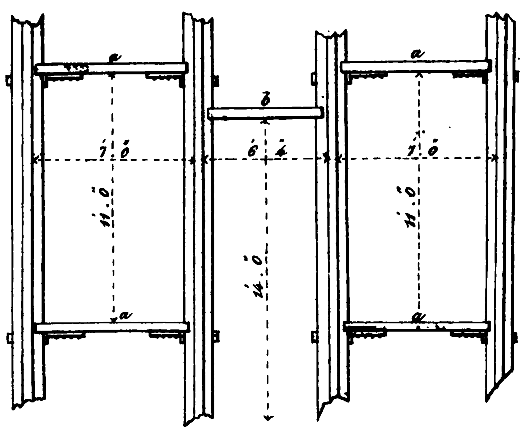
Section.



Permanent Way in Embankment.



Plan.



From the above rules and examples it will be seen that the steadiness of the carriages composing a train must be very considerably affected by any variation in the distance between the rails, or in the height of one rail above the other when not intended to counteract the effect of a curve; and the importance of laying the rails and sleepers (that is, the permanent way) in the most solid and substantial manner will be at once perceived. With the view of attaining this end, several different methods have been devised for fixing and supporting the rails; these may all, however, be generally classed under two heads, viz., those having a continuous bearing, or in which the rails rest upon wooden sleepers throughout their entire length, and those which are only supported at certain intervals (varying from 2 feet 6 inches to 5 feet as given in the table at page 49), on metal chairs, as they are technically termed.

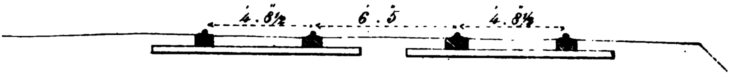
The Great Western was the first line on which the continuous bearing was employed, this method of laying the rails having been suggested by Mr. Brunel, who is the engineer of that line. The method there adopted is shown in figure 63; the rails (the form of which has been already given at *g*, figure 59) are firmly screwed to a piece of timber 15 inches in width, 7½ inches in depth on the outer side, and 7 inches in depth on the inner, by which means the rail is made to slope somewhat inwards to counteract the spreading tendency produced by the conical wheels. A piece of patent felt is

interposed the whole way between the rail and the timber, forming an elastic bed for the rail. The longitudinal timbers are preserved at their correct distance apart by transverse pieces (*a*, *a*,) placed between them at every 11 feet, being notched into the timbers on both sides, and further secured to them by wrought-iron knee straps. Similar pieces (*b*, *b*,) are also placed at distances of about 14 feet apart, between the two lines of railway, in order not only to preserve them at their proper distance, but to steady the whole. The ground immediately under the sleepers, and upon which they bed (technically called the *ballasting*), should be composed of clean gravel, broken stone, burnt clay, or any other hard material not affected by wet; it should be well rammed and packed under the rails, and its upper surface should be formed in the manner shown in the section, so as to lead off any water which may fall upon it, and prevent its soaking through to the timber. The continuous bearing has been adopted on other lines besides the Great Western; amongst which may be mentioned the Newcastle and North Shields Railway and the Croydon Railway, the method adopted upon the latter of which is shown in figure 64. The form of the rails is shown at *h*, figure 59; they are screwed to longitudinal sleepers 12 inches wide and 6 inches in depth, which are again supported upon cross sleepers 9 feet in length, 9 inches in breadth, and 4½ inches in depth; these sleepers are placed 3 feet apart from center to

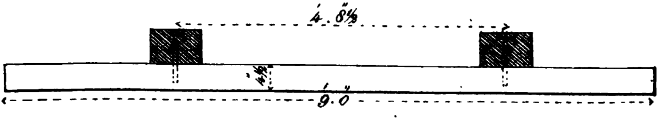
CROYDON RAILWAY.

Fig. 64.

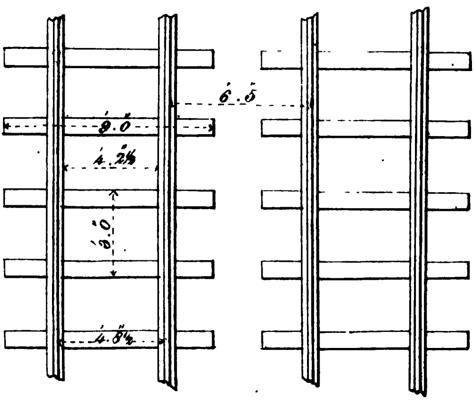
Section.



Permanent Way in Embankment.



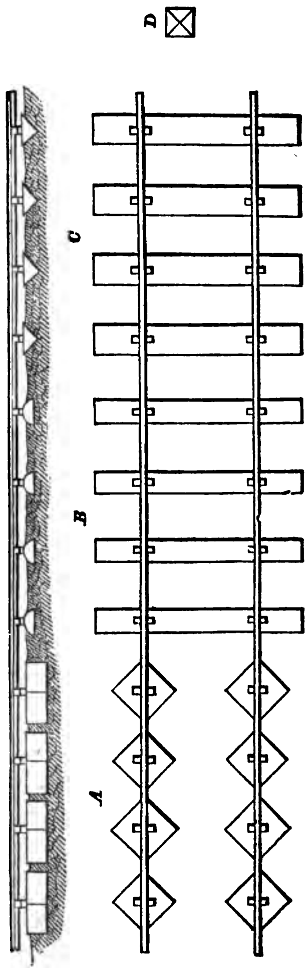
Plan.



center, and are securely spiked to the longitudinal timbers.

The system, however, which has been most generally adopted is that of fixing the rails in iron chairs supported upon sleepers placed at certain intervals, according to one of the methods shown in figure 65. That shown at A is the mode in which the London and Birmingham and many other lines were laid in those portions which are in cutting, and it consists in fixing the chairs supporting the rails to blocks of stone, usually from 4 to 5 cubic feet in bulk, which are firmly imbedded in the ground; they were most frequently laid diagonally, as shown at A. This method has, however, been in a great measure superseded, and

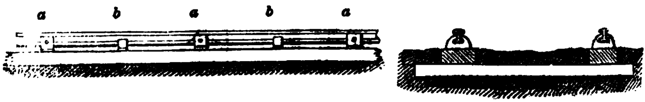
Fig. 65.



timber sleepers are almost universally employed at the present time. The form of timber sleeper most generally employed is that shown at B, being a piece of round timber between 9 and 10 feet in length, and about 12 inches in diameter, sawn down the middle and laid with the flat side downwards, a flat bed being adzed out on the upper side for each of the chairs. Another form of sleeper (as shown at C) has been employed by Mr. Cubitt on the South Eastern Railway, which consists of a piece of square Baltic timber sawn twice diagonally, as shown at D, so as to produce four sleepers, which are laid with their broad flat face uppermost.

A combination of the two systems has been adopted on the Birmingham and Gloucester Railway, and upon the Dublin and Kingstown Railway, the former of which is represented in figure 66.

Fig. 66.



In the cuttings the rails are supported upon chairs (*a*, *a*, *a*,) and saddles (*b*, *b*,) placed alternately, and fixed to longitudinal timbers 13 inches wide, and 6 inches in depth; and on the embankments the saddles are replaced by chairs, which are only 30 inches apart; and the longitudinal timbers are connected together by transverse sleepers 7 feet 2

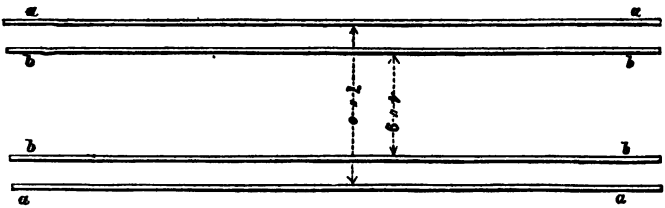
inches in length, 7 inches in width, and 3½ inches in depth, as shown in the cross section. The chairs weigh eighteen pounds, the saddles only three, and they are placed at a distance of only 2 feet 6 inches apart.

We have as yet only mentioned incidentally the *gauge* of railways, by which is technically meant the distance between the two rails. It is an unfortunate circumstance that, previous to the formation of any important lines of railway in this country, the whole subject had not been properly investigated, and that gauge adopted which, after such an examination, appeared best qualified to satisfy the wants of the public, and to meet the requirements of trade. And such a gauge having been fixed upon, its uniform adoption should have been made compulsory, and no consideration should have induced a departure from it. The following table exhibits the various gauges which have been adopted in different parts of the United Kingdom; the 4 feet 8½ inches, the 4 feet 8¾ inches, and the 4 feet 9 inches gauges may be regarded as the same, since the same carriages travel over them without inconvenience; in fact, the latter is now almost always adopted as affording a little more play between the rails and the flanges of the wheels. In this table no notice is taken of the 5 feet gauge adopted on the Eastern Counties and the London and Blackwall Railways, as those lines have subsequently been altered to the 4 feet 9 inches gauge.

Name of Railway.	Gauge.		Central space between the two lines.		Total width of the Railway.	
	ft	ins.	ft.	ins.	ft.	ins.
Brandling Junction	4	8½	5	2	24	6
South Western	4	8½	6	5	25	0
Liverpool and Manchester . . .	4	8½	5	2	25	7
Midland Counties	4	8½	6	5	26	0
Birmingham and Gloucester. . .	4	8½	6	0	30	0
London and Birmingham . . .	4	8½	6	5	30	0
Dublin and Kingstown	4	8½	7	4½	30	0
London and Croydon	4	8½	6	5	33	10
Chester and Crewe	4	8¾	6	5	30	0
North Midland	4 8¾ and 4 9		6	5	33	0
London and Brighton	4	9	6	5	24	0
Manchester and Birmingham . .	4	9	6	5	29	0
Chester and Birkenhead, and the Manchester and Leeds . . .	4	9	6	5	30	0
Arbroath and Forfar	5	6	6	5	28	6
Ulster Railway	6	2	6	4	33	0
Great Western	7	0	6	6	30	0

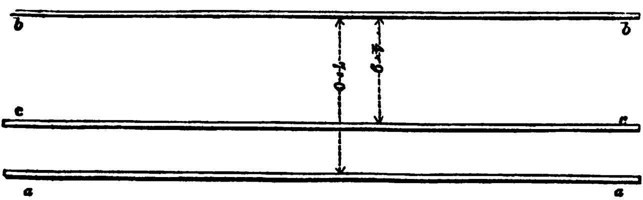
Much practical inconvenience and great interruption to trade result from this difference in the gauges of different lines of railway, in consequence of its necessitating the removal of passengers and goods from the carriages of one gauge to those of the other. In order to remedy this inconvenience, it has been suggested to form those lines of railway which communicate with both broad and narrow gauge lines, with a mixed gauge, which may be done in two different ways. That shown in fig. 67 is to lay the narrow-gauge line in the center of the broad, each having its own distinct lines of rails, *a a* being

Fig. 67.



those belonging to the broad gauge, and *b b* those of the narrow. While, however, this method possesses the advantage of allowing a mixed train of narrow and broad gauge carriages to be run upon the line, it is more expensive than that shown in fig. 68,

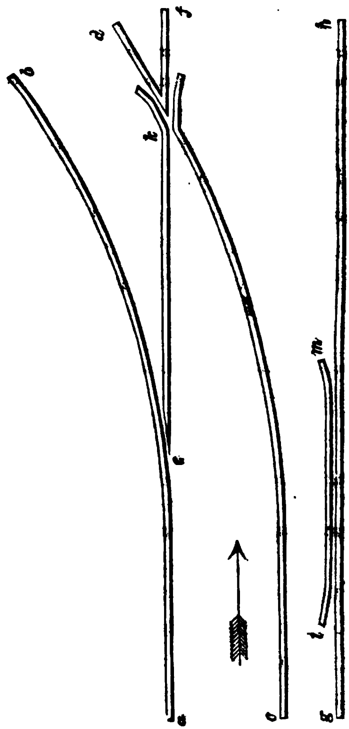
Fig. 68.



and would require a more complicated arrangement for crossing on to another line of rails. The latter method is to lay a third rail, *a a*, outside the narrow-gauge line, at such a distance from it, that while the two rails *b* and *c* form the narrow-gauge track, *a* and *b* form the broad-gauge. This latter method has been adopted on that portion of the Birmingham and Gloucester Railway which extends from Gloucester to Cheltenham. The Birmingham and

Gloucester Railway is (as stated in the foregoing table) a narrow-gauge line, and Cheltenham is the first station upon it out of Gloucester. The Great Western Railway Company having determined to extend their broad-gauge line from Gloucester to Cheltenham, availed themselves of the existing narrow-gauge line by laying a third rail on the outer side in the manner shown in fig. 68. At a short distance from the Cheltenham station of the Birmingham and Gloucester Railway, they leave that line, and run by a branch of about a mile in length into the town of Cheltenham. Fig. 69 shows the way in which the rails are arranged at the point where the two lines separate, so that while the narrow-gauge trains pass along their old track, the broad-gauge

Fig. 69.

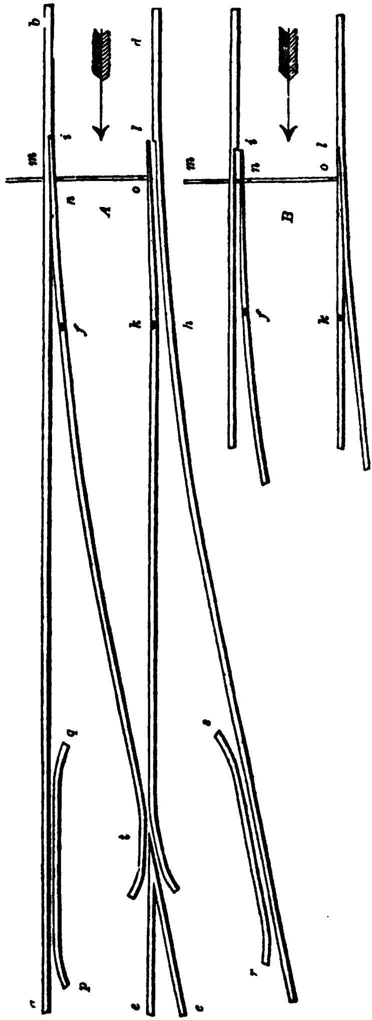


are caused to leave the same and turn off on the branch line without any person's attendance. *a b* and *c d* are the rails of the old narrow-gauge line, *e f* and *g h* those of the broad gauge, the latter *g h* being the continuation of the additional outer rail. It will be observed that the line of rail *a f* is cut through at *e* and at *k* in order to allow the flanges of the wheels belonging to the narrow-gauge trains to pass; and in like manner the rail *c d* is cut through at *k* in order to allow those of the broad-gauge carriages to pass. Now, when a narrow gauge-train approaches the point *e*, the flanges of the wheels are kept close to the rail *a b* by the opposite rail *c d*, and they are made to pass through the cut at *e*, the train pursuing its course along the old line. When, however, a broad-gauge train arrives at the same point, the wheels are drawn over towards the rail *g h*, by a *guard rail* (as it is termed) *l m*, which acts on the inner side of the flanges of the wheels, by which means they are prevented from passing through the cut in the rail at *e*, and are made to travel along the lines *a f* and *g h*. It will be observed that the rails where they terminate at *k*, *l* and *m*, are made with an enlarged opening in order to guide the flange of the wheels with greater certainty in the intended course.

It is frequently necessary to pass trains from one line of rails to another, and several different methods have been devised for doing this. One of the simplest and most frequently-adopted plans, is to lay

down a short line of rails, connecting the other two, and so establishing the desired communication. It becomes necessary however, then, to have the means of connecting and disconnecting this short line with the main line at pleasure, according as it is intended that the train should leave or continue upon the latter; and this is effected by means of a contrivance termed a *switch*, which is shown in fig. 70: *a b* and *c d* are portions of the rails of the main line, and *e f* and

Fig. 70.

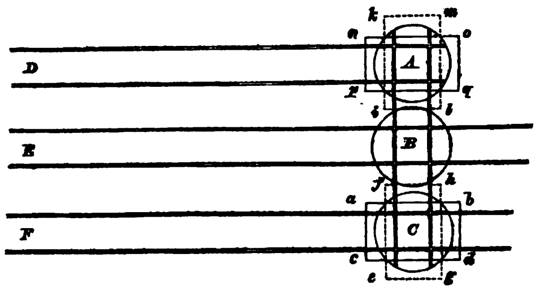


g h portions of the short line branching from it, all of which are immovably fixed in the ordinary manner, with the exception of the two rails *f i* and *k l*; these, which are termed the *tongues* of the switch, are only fixed at one of their ends, *f* and *k*, on which they turn as centers; their other ends are tapered away to nearly a point, a slight recess being cut in the other lines, at *i* and *l*, into which they fit. These tongues are connected together by a bar, *m n o*, by means of which they are always preserved at such a distance apart, that when either of the tongues is in contact with the rail near it, the other shall be removed from the opposite rail sufficiently to leave space for the flange of the carriage-wheels to pass between them. In order, then, to cause a train to pursue its course along the main line, or to leave the same and enter the branch line, it only becomes necessary to move the bar *m n o*, which, when in the position shown at A, will cause the carriages to leave the main line, but if shifted into the position shown at B, will cause them to continue their course along the same. It is usual to have the switches so arranged that they are kept in the position shown in B (in which the main line is not interrupted) by a self-acting weight, the attendance of a man to move them into the position shown at A being necessary when it is desired that the train should leave the main line. Two guard rails, *p q*, *r s*, are necessary in order to prevent the flanges of the wheels from

striking against the point where the two lines intersect each other.

Another method of removing only single carriages from one line of rails to another, is by means of what is termed a *turntable*. Three of these are shown in fig. 71, at A, B, and C. They consist of a

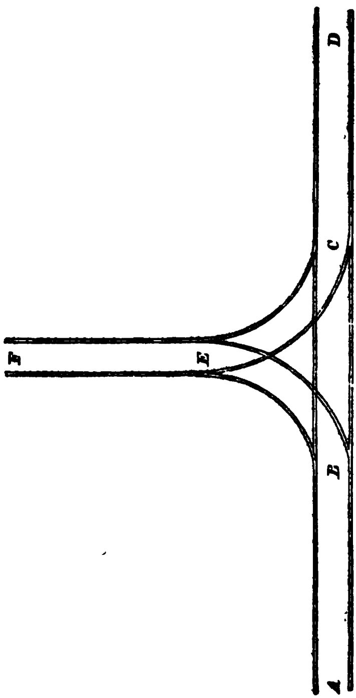
Fig. 71.



circular platform of timber or iron, supported on wheels, and fixed upon a center, in such a manner that they are capable of being turned round, even when loaded with a considerable weight, without much friction. On their upper surface they have usually two lines of rails crossing at right angles, and they are so placed that these form the continuation of the main lines of the railway, and another line crossing these at right angles, as shown in the figure. Now, the way in which these are employed is as follows: supposing that a number of carriages situated on the line F C were required to be removed on to the line D A, the carriage nearest C would be

moved on to the turntable C, (which, it should have been stated, is of sufficient diameter to receive the whole of the carriage upon it,) and brought into the position shown by the whole lines, *a b c d*, the turntable would then be turned upon its center through a quarter of a circle, by which the carriage would be brought into the position shown by the dotted lines *e f g h*; it would then be run over the turntable B, on to A, into the position shown by *i k l m*, and the turntable A being turned upon its center, would bring the carriage into the position shown by the whole lines *n o p q*, in which it would only have to move down the line of rails to D; and the same method of procedure being followed with the other carriages, the whole train would in a very

Fig. 72.



short time be shifted from one line to the other. If it had been desired to bring the carriage on to the center line of rails, then the turntable B would have been employed instead of A.

A simple method of reversing a train of carriages is shown in fig. 72, which consists in forming a short branch, E F, at right angles with the main line, and communicating with it by two curves, B E and E C. The train has only then to be run off the main line, by the curve B E, into the branch, until the last carriage has cleared the point E, when the switches are altered, and the train returned to the main line by the other curve, E C, by which the whole train will have been reversed, the end which before was towards A being now towards D.

The limits of the present work will not allow us to enter at length into the minute details of construction which are requisite in the various parts of an extensive line of railway, to the mechanical ingenuity, beauty, and simplicity of which we, in a great degree, owe the present state of perfection which railway travelling has attained*. It is, in fact, very interesting to look back over the short period which the history of railway locomotion occupies, and observe how rapid and unexpected its progress has been, so much so, that it is little more than twenty years since the following observations were penned by a mechanical writer of justly-acquired celebrity, whose

* For further information on this point we must refer to the Rudimentary work on Railways by Mr. Stephenson.

knowledge of the subject was very extensive, and who was by no means predisposed to take a narrow view of it. He remarks—"We speak of this [ten miles per hour] as a rapid motion, and the more we consider the subject, the more reason we find to consider it so, and we see no material advantage in a greater speed, unless it were on a railway for messengers and letters only, where the small carriage to contain the messenger and letters may be impelled by a man, seated in it so that he could work in a manner similar to a man rowing. On a railway adapted for such a light carriage, with its load suspended below its axles, a great speed might be obtained, *when habit had rendered it supportable;* and perhaps it may in a few rare instances be worthy of trial, where the quick transmission of intelligence or despatches is of importance: and, being successful in these instances, it might be adopted for the conveyance of mails; *but that any general system of conveying passengers would answer to go at a velocity exceeding ten miles an hour, or thereabout, is extremely improbable.*"* How great a contrast between the opinions here expressed, and the present state of railway travelling; when a train of several tons, and containing, perhaps, some hundreds of passengers, is conveyed (not as an experiment, but daily) at the rate of fifty or sixty miles an hour, with perfect safety and ease.

* Tredgold on Railways, p. 119.

CANALS.

Of their General Arrangement.

CANALS are artificial channels of water, which have been formed for the purpose of affording the facilities of water conveyance in districts where no natural rivers and streams exist, or where those which may have existed have, from a variety of causes, been ill adapted for navigable purposes. And, in fact, canals possess (generally speaking) so many advantages over rivers, that they have frequently been constructed, at considerable cost, in situations where navigable rivers were already existing. In many rivers the existence of currents and shoals renders the navigation difficult and uncertain, and in times of floods and freshets, it has frequently to be entirely suspended. It may also be remarked that rivers seldom flow in a very direct course, but more frequently pursue a winding path, depending upon the form of the valleys through which they have to thread their way: in such situations as these, the superiority of canals is sufficiently obvious.

In laying down and arrangin the general line of a canal, many points have to be considered in addition to those which have been generally mentioned, as applying to them in common with roads and railways, at the commencement of this chapter. One of the most desirable points to be attained is a per-

fectly level surface throughout its whole extent. It is, however, very seldom that the country is so favourable as to allow this to be effected. In most cases it becomes necessary occasionally to alter the level of the surface of the canal, the water being retained at the higher level by gates so placed that the pressure of the water against them keeps them closed. It is, however, impossible to prevent a small amount of leakage at the gates, and therefore it becomes necessary to have the means of supplying the upper portion of the canal with water, to compensate for that which thus escapes, as well as that which is necessary (as we shall presently explain) to pass vessels from the higher to the lower level. In addition to these two causes of loss, a further waste is occasioned by the evaporation from its surface, and the absorption of the water by the ground through which it flows. It is, therefore, an object of considerable importance in the arrangement of a canal, to obtain some natural *feeder* (as it is termed) for the supply of the water thus lost, and which object is usually attained by diverting some of the smaller natural rivers or streams, and leading as much of their waters as may be required to supply the highest (technically called the *summit*) level of the canal, for that being properly supplied, the lower levels will be fed by the water which escapes from the upper. Before forming a canal, the strata through which it will pass should be carefully examined, more especially with reference to its powers of retaining water,

that is, of not absorbing it. Many soils, such as clean sand, or gravel, would carry off the water so rapidly as soon to drain the canal, and therefore such strata should, if possible, be avoided. Where, however, it is impossible to do so, the canal may be made water-tight, by lining its sides and bottom with *puddled* clay, which consists of good clay, thoroughly well beaten up with water, or *tempered*, and then mixed with a certain proportion of gravel, sand, or chalk. Pure clay by itself would not answer, because if at any time the water in the canal sunk below its ordinary level, the upper part of the puddle, becoming dry, would crack; and when the water again rose it would escape through these cracks, which by its action would be gradually enlarged, until the puddle was rendered useless.

The form of section of a canal, that is, its width and depth, is another point requiring to be carefully considered. This must depend upon the size of the vessels which are to be conveyed upon it, and upon the amount of the traffic to be expected. The sides of canals are usually formed with slopes, of about two to one, and, in some cases, the upper parts, near the water's edge, and which are most exposed to the ripple produced by the passage of vessels, are protected by rough stone paving.

The following table exhibits the length and dimensions of the transverse section of a few of the English and American canals:—

NAME OF CANAL.	Date of construction	Length in Miles.	Breadth.		Depth.	ENGINEER.
			Top.	Bottom.		
ENGLISH.			Feet.	Feet.	Ft. In.	
Sankey Canal........	1755	12	48	..	5 7	John Eyes.
Leeds and Liverpool..	1770	108¾	42	27	5 0	Brindley.
Basingstoke.........	1778	37	38	..	5 6	....
Thames and Severn ..	1783	30	42	30	5 0	R. Whitworth.
Gloucester & Berkeley	1793	16½	70	..	18 0	Telford.
Grand Junction	1793	90	43	..	5 0	Jessop.
Kennet and Avon	1794	57	44	24	5 0	Rennie.
Aberdeenshire........	1796	18½	23	..	3 9	Captain Taylor.
Thames and Medway	1800	8½	50	28	7 0	....
Caledonian	1803	23	40	..	20 0	Telford.
Rye, or Royal Military	1807	30	72	36	9 0	Royal Engineers.
AMERICAN.						
Champlain	....	11	40	28	4 0	....
Schuylkill Navigation	....	58	36	22	3 6	....
Morris	....	101¾	32	20	4 0	....
Pennsylvania	....	276¼	40	28	4 0	....
Erie	....	363	40	28	4 0	....

Of Locks, and their Substitutes.

We have already mentioned that, in cases where it is necessary to alter the level of the surface of a canal, the water is retained at the higher level by means of gates; and we have now to explain, more in detail, the manner in which they are constructed, as well as the means adopted for passing vessels up or down from one level to the other.

The most frequently-employed contrivance for this purpose is the common *lock*, of which fig. 73 is a longitudinal section; fig. 74 a plan; fig. 75 a transverse section through the center of the lock; and fig. 76 a transverse section of the canal below the lock, showing its lower entrance. The upper and lower portions of the canal are connected by the passage A B C, termed the lock chamber, the form of which will be seen from fig. 75; its sides and bottom

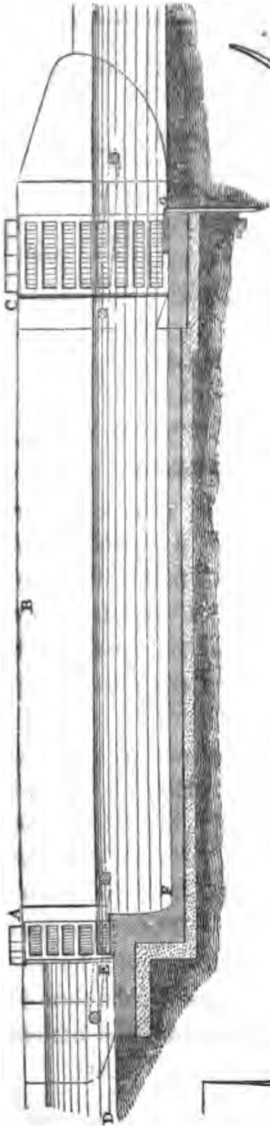


Fig. 73.

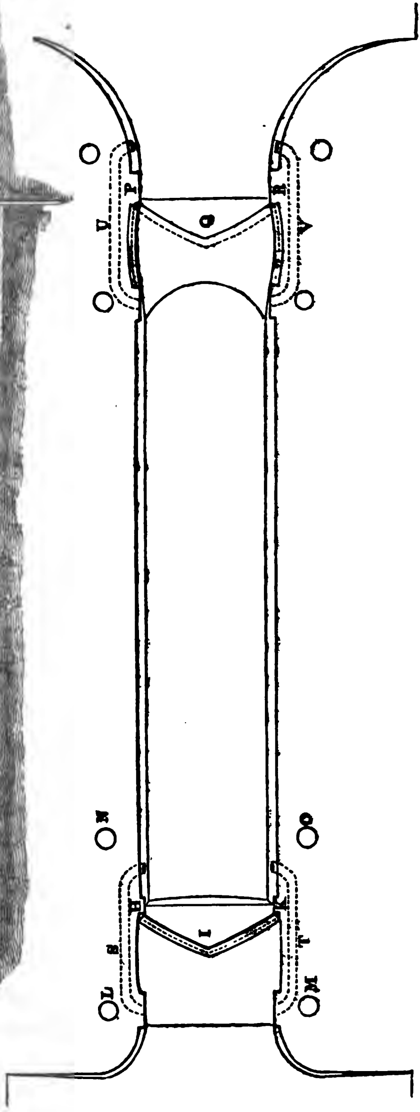


Fig. 74.

Fig. 75.

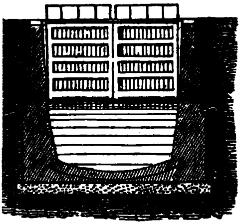
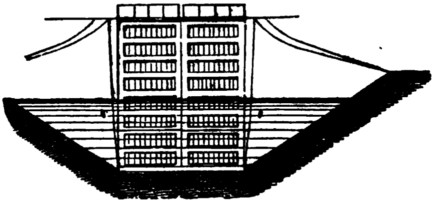


Fig. 76.



(the latter termed the *invert*, or *floor*,) are usually lined with brick or stone. The lock chamber is much less in width than the canal, being made only a little wider than the vessels intended to pass through it. It will be observed, by reference to fig. 73, that the floor of the upper end of the lock chamber, from D to E, is on the same level as the upper portion of the canal; and the remainder, from F to G, is level with the bottom of the lower canal. The gates, by means of which the water is retained at the upper level, are shown at A E, and in the section, fig. 75; they are slightly curved, as shown in the plan, fig. 74. When opened, they turn upon their ends, H and K, as centers; and they are of such a breadth that, when shut, they meet at an angle at I, in which position each gate derives support from the other; and the pressure of the water against them only tends to keep them the more closely shut, and, consequently, to diminish the space through which it might otherwise have escaped.

In this arrangement the gates are precisely in a similar situation to the two beams shown in fig. 15*,

* Page 37 of the First Part.

the pressure of the water against the gates taking the place of the weight suspended from the beams, and acting (in the manner there explained) as a force against the sides of the lock chamber, tending to push them apart. So long, however, as the walls are made sufficiently strong to support the thrust thus brought upon them, no inconvenience arises. The gates are opened by means of capstans, L and M, the chains being attached to the gates under the water, and passing through tunnels in the sides of the lock. They are closed in a similar manner, by two other capstans, N and O, the gate H I being shut by means of the capstan O, and K I by means O N.

Another pair of gates, precisely similar, are placed at the lower end of the lock, C G; they are carried up to the same level as the upper gates, and are therefore as much higher than those as the upper canal is above the lower, as is shown at A and C, fig. 73, and in the two sections, figs. 75 and 76.

We will now proceed to explain the mode in which the lock is used; and we will first suppose the case of a boat requiring to be raised from the lower to the upper level of the canal. The lower gates, at C, are first opened, as shown in figs. 73 and 74, and the boat is floated into the lock chamber, (the length of which should be a few feet more than that of the longest boat passing along the canal,) they are then shut, and brought into the position shown by the dotted lines P, Q, R, in fig. 74, which having been

done, some of the water from the upper canal is let into the lock chamber, through channels shown at S and T, in the sides of the upper part of the lock, and which can be opened and closed at pleasure, by sluices worked by machinery. The water being prevented from flowing out, in consequence of the lower gates being shut, quickly rises to the same height in the lock chamber as in the upper canal, the boat rising with it. As soon as such is the case, the upper gates at A are opened, and the boat is floated out of the lock into the upper canal. The reverse operation of lowering a boat from the upper to the lower level, is performed in a similar manner; the boat is floated into the lock chamber, the gates at A being opened, and those at C closed; the former are then shut, and the water in the lock chamber is allowed to run out by channels, U V, formed at the lower end of the lock, similar to those already described at the upper, until level with the surface of the lower canal, when the gates at C are opened, and the boat passes out of the lock.

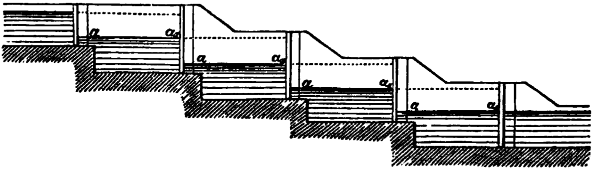
The quantity of water let out of the upper canal in the passage of a boat depends upon the direction in which the boat is moving, and whether it finds the lock filled or empty. The following Table shows all the cases which can occur:—

	Finding the Lock,	Lets out of the Upper Canal,	And leaves the Lock,
Boat descending	Full. . . Empty .	None .... 1 Lockfull...	Empty.
Boat ascending .	Full. . . Empty .	1 Lockfull... 1 Lockfull...	Full.

It is therefore evident, that a series of boats following each other in the same direction, either up or down, will require one lockfull of water for every boat that passes; but if the boats pass alternately up and down, only one lockfull will be required between each pair, since every ascending boat requires a lockfull, and leaves the lock full; and every descending boat finding the lock full, does not require any water from the upper canal.

When the ground rises or falls so rapidly as to require several locks in a short distance, it is not unusual to form what is called a *chain of locks*, or to make a succession of lock chambers immediately contiguous to each other, the lower gates of one chamber forming the upper gates of the next below it, as shown in fig. 77. The advantage of this

Fig. 77.



arrangement is a considerable saving in the cost of constructing the locks, arising from the circumstance that only one more than half the number of gates, with all the machinery for opening and closing them, is required. Where, however, there is a scarcity of water for the supply of the upper level of the canal, this advantage is counterbalanced by the disadvantage of this arrangement of the locks requiring a larger quantity of water for the passage of the boats under certain circumstances, as will be seen from the following Table:—

	Finding all the Locks,	Lets out of the Upper Canal,	Leaves all the Locks,
Boat descending	Full. . . Empty.	None.......... 1 Lockfull....	Empty.
Boat ascending .	Full. . . Empty.	1 Lockfull.... 4 Locksfull *.	Full.

In this table it is not meant, when the locks are said to be empty, that they have actually no water in them, but that the water is then at its lower level, as shown by the lines $a\ a_1$, in fig. 77. From this table it therefore appears that, if a succession of boats follow each other in the same direction, whether upwards or downwards, each boat will require one lockfull of water; but if they pass alternately up

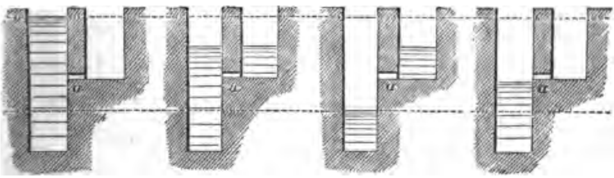
* That is, as many locksfull will in this case be drawn from the upper canal as there are contiguous lock chambers, which, in the present example, is four.

and down, each pair will require between them as many locksfull as there are contiguous lock chambers, or, in the present example, four locksfull; for, the previous descending boat having left all the locks empty, the ascending boat will require four locksfull; and, as it leaves all the lock chambers filled, the next descending boat will not draw off any water from the upper lock. It will therefore be seen that, with single locks, the alternate passage of boats in contrary directions requires *less* water than their consecutive passage in the same direction, but with a chain of contiguous locks, *more* water.

In some situations, where the supply of water for lockage is small, a system has been adopted by which the quantity required for this purpose is much lessened. This system, which is shown in figs. 78 and 79, consists in forming one or more excavations or ponds by the side of the lock chamber, with which they are connected by culverts, having sluices, or valves. The level of these ponds is so arranged that when the lock is full, and it is desired to let off the water, so as to lower its surface to the level of the lower canal, instead of allowing the whole of the water to run into the canal, a portion of it is run into the pond, and there kept until it is again desired to fill the lock chamber, when, instead of taking the whole of the water required for that purpose from the upper canal, that from the pond is first allowed to run into the lock, and the remainder only taken from the upper canal.

Figure 78 exhibits four different sections of a lock with one side pond, showing the relative levels of

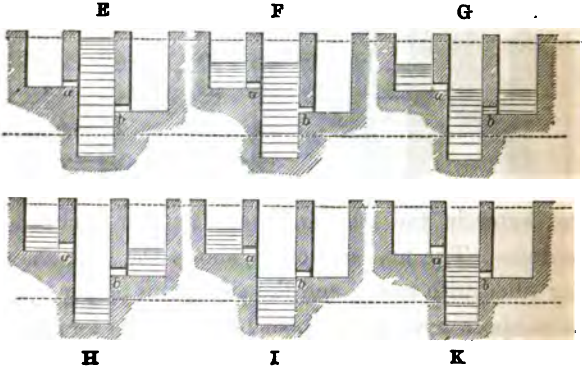
Fig. 78.



the water in the lock and pond at four successive periods. The first section, A, shows the lock chamber filled with water, and the side pond empty. Let us suppose now, that, a boat being in the lock, it is desired to lower it into the lower canal, in which case, instead of allowing the water to run into the canal, the sluice *a* is opened, and the water allowed to run from the lock into the pond, until its surface has attained the same level in both, as shown at B; the sluice is then closed, and the remainder of the water allowed to escape into the lower canal. In this stage, section C shows the relative level of the water in the lock and side pond. If now it is wished to refill the lock, instead of doing so entirely from the upper canal, the sluice *a* is opened, and the water which has been retained in the pond is allowed to run down into the lock, as shown in section D; the sluice *a* being then closed, the remainder of the water is drawn from the upper level of the canal. The arrangement shown in fig. 78, with only one side pond, saves one-third of the water which would

have been required to fill the lock every time from the upper canal; but that shown in fig. 79, in which

Fig. 79.



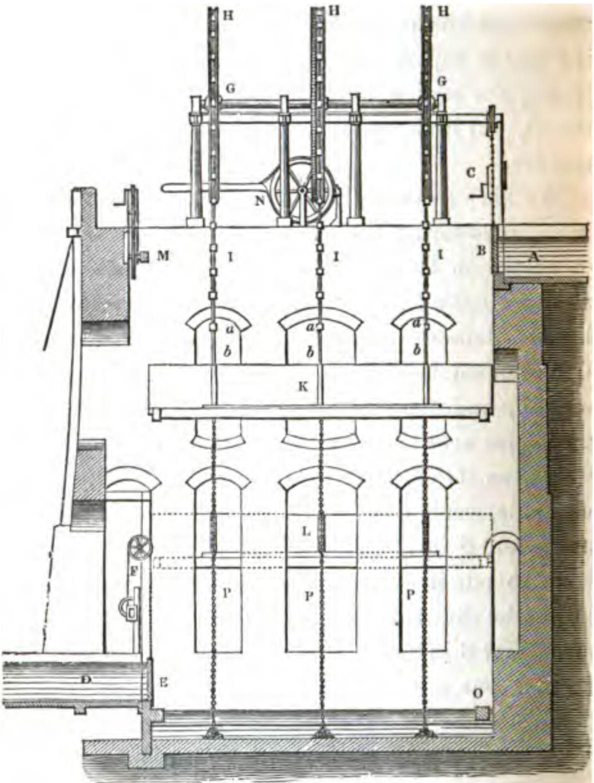
there are two side ponds at different levels, saves half the water which would have been required without them. In this case, section E shows the lock filled with water. The sluice *a* being then opened, the water enters the left-hand pond, until it has attained the level shown in section F, when the sluice *a* is closed, and *b* is opened, allowing the water to enter the right-hand pond, as shown in section G; the sluice *b* is then closed, and the remainder of the water allowed to run off into the lower canal, until it has attained the level shown in section H. If now it is required to refill the lock chamber, the sluice *b* is first opened, and the water is allowed to run out of the right-hand pond, as shown in section I; the sluice *b* is then closed, and *a* opened, and the water from the left-hand pond likewise admitted into the

lock, by which it becomes half filled, as shown in section K, only the other half requiring to be drawn from the upper canal. In both the arrangements which we have now described, the statement of the water saved is upon the assumption that each pond is equal in superficial area to the lock chamber; if larger, the saving would be greater than has been stated, but if the ponds are less, the saving will be smaller.

We have as yet only noticed one method of raising and lowering the vessels navigating canals, and now pass on to describe a very ingenious arrangement for *lifting* the boats perpendicularly, contrived by Mr. James Green, and applied by him on the Grand Western Canal. Figure 80 is a longitudinal section, and fig. 81 half a front view, and half a transverse section; A is a portion of the upper canal, which, as it approaches the lift, is divided into two channels, each of which is about 7 feet in width, and 3 feet 6 inches in depth, being only just sufficient to admit of the passage of one of the canal boats, the dimensions of which are 26 feet in length, and 6 feet 6 inches in width; they are built to carry about 8 tons, and, when laden, do not draw more than 2 feet 3 inches of water. These channels are closed by a door or gate at B, fitting with sufficient accuracy to prevent the escape of any of the water, but, at the same time, admitting of being opened by means of the machinery shown at C, which raises the gate vertically in a groove in the framework on each side.

An end view of one of these gates is seen in the left-hand half of fig. 81. The lower canal is also divided,

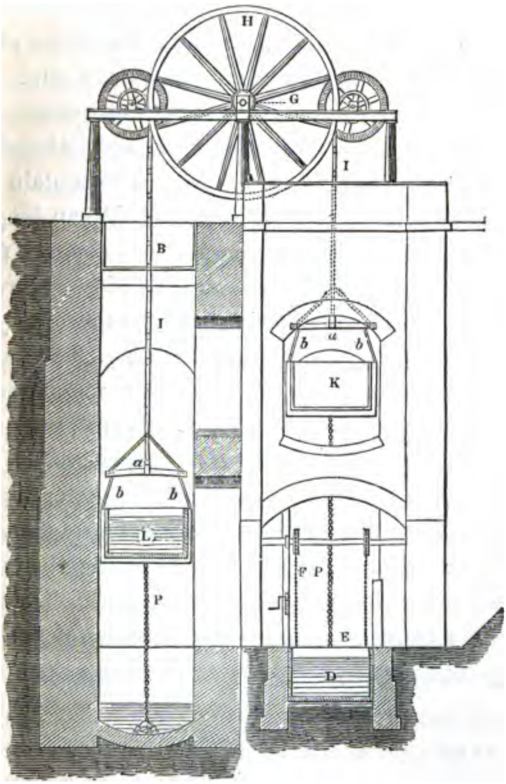
Fig. 80.



in a similar manner, into two channels of the same dimensions, (one of which is seen in section at D,) and they are closed in the same way by means of

gates, E, E, the machinery for raising which is seen at F. In the space between the upper and lower canals, two long narrow chambers are formed, one corresponding with each of the channels of the canals. A transverse section of one of these chambers is seen in the left hand half of fig. 81, and a

Fig. 81.



longitudinal section in fig. 80. Along the top of these chambers, supported on iron columns, is placed an axle or shaft, G G, the center of which corresponds with the center of the pier dividing the two chambers. Upon this axle three wheels, H, H, H, are securely fixed, the diameters of which are such, that chains I I, hung in grooves in their circumferences, hang exactly down the center of each chamber. These grooves are made to fit the links of the chain in such a manner that the latter cannot slip. To the end of these chains are attached two water-tight tanks or cradles, K and L, (one in each chamber,) the dimensions of which are sufficient to contain one of the boats navigating the canal*. By an inspection of fig. 81, it will be seen that the chains I I are attached to a cross-bar, *a*, connected with the cradle by two rods, *b b*, and leaving sufficient headway to allow the boat to pass freely under them. The length of the chains I I, is so adjusted, that when one of these cradles is level with the upper canal, the other is on the same level as the lower, and *vice versâ*. When it is desired to lower a vessel from the upper to the lower canal, one of the cradles is brought up to the same level as the upper canal, and is there secured by being forcibly screwed up against the entrance of the channel A, by means of machinery at M, with sufficient force to prevent the escape of any water between them; the

* Each end of these tanks is closed by a gate, or door, similar to those at B and E, and which are opened in a similar manner, by sliding in vertical grooves.

gate of the cradle is then connected, by means of a bolt, with that of the channel A, and the two are raised together by the machinery at C, to a sufficient height to allow the boat to pass under them from the upper canal into the cradle K, in which it floats precisely as it did previously in the canal. The doors or gates are then lowered into the grooves in which they fit, so as securely to close the ends of the channel and the cradle. Previous to the passage of the boat into the cradle K, both it and the lower one, L, being filled to the same height with water, and both being of the same dimensions, they were of the same weight, and therefore mutually balanced each other; because, from the manner in which they are hung, by chains over wheels, (perfectly free to move,) if they were not of equal weight the heavier would descend, drawing up the lighter on the opposite side. Now it would, at first sight, appear reasonable to suppose that, although the cradles, when both empty, or filled to the same height with water, balanced each other, they would cease to do so when a boat was placed in one of them; but it must be remembered, that the boat occupies a considerable space in the cradle which had previously been filled with water, but which, as the boat passed into it, escaped into the upper canal; and it is an established fact in hydrostatics, that the weight of water thus displaced by a boat, or any other *floating* body, is precisely equal to that of the boat itself; so that, although the cradle has received the additional weight of the

boat, it has lost precisely the same weight of water, and, consequently, the two cradles are still in equilibrium, or, in other words, still balance each other. In order, however, that the cradle K may descend, it is necessary to give it a slight preponderance, or excess of weight over L, and this is very easily effected by allowing a small quantity of water to escape from the lower cradle, L, by which it is rendered lighter than the other, so that upon the screw at M (by which the upper cradle was retained) being relieved, it commences its descent, being regulated in speed by means of a brake, shown at N. As soon as the cradle K reaches the level of the lower canal (into close contact with which it has been brought by a wedge placed at O, which forces it, over against the end of the channel), the gate E is connected with the gate at that end of the cradle, and the two being raised together, the boat floats out into the lower canal. We must not omit to mention a simple contrivance for making the suspension chains, I I, always balance; it is evident, that it is only when the cradles are on the same level that there will be an equal length (and consequently weight) of chain hanging on both sides of the wheels H, H, but that when either of the cradles is in its highest position, and, having to descend, it is required to be the heavier, it will really be lighter in consequence of the short length of chain by which it is suspended this difficulty is, however, simply removed by hanging from the bot-

tom of the cradles three chains P, P, P, the weight of which is precisely the same, per foot, as those (I, I,) by which the cradles are suspended, and which are of such a length, that when the cradle is in its highest position they reach to the bottom of the chamber; thus, as the length of chain above the cradle diminishes, that below it increases, the total length always being the same.

The advantage of this method of passing boats from one level to another, compared with the system of locks, is a saving in the first cost of construction, and in the time, and quantity of water required. The height of the lift which we have just described is 46 feet, and the time required for raising or lowering a boat is about 3 minutes; whereas, with the usual system, five or six locks would have been used to attain the same lift, the time in passing which would have been nearly half an hour. With regard to the quantity of water consumed, setting aside that lost by leakage and in working the lift, a quantity of water precisely equal to the weight of the boat passes either up or down the lift in a contrary direction to that of the boat; so that if the traffic in both directions is equal, no water will be taken from the upper canal*.

On some of the American canals inclined planes have been employed instead of locks, for conveying boats from one portion of a canal to another at a

* For a more elaborate description and plates, the reader is referred to the Transactions of the Institution of Civil Engineers, vol. ii., page 185.

different level. On the Morris Canal there are 22 of these inclined planes. They consist of a kind of railway, having an inclination of 1 in 21, the rails being of iron, and extending for some distance into the lower canal, and at their upper extremity terminating in a kind of lock chamber. Upon this railway there is a timber carriage supported by a truck at either end, of sufficient dimensions to carry one of the boats which navigate the canal, and which are about 70 feet in length, 8½ feet in breath, and contain about 30 tons. When it is desired to raise a boat, this carriage is run down upon the railway into the lower canal, and passed under the boat, which, having been secured to it by chains, the carriage, with the boat upon it, is drawn up the inclined plane by machinery, into the lock at its upper extremity, the lower gates of which are then closed, and the water being admitted from the upper canal, the boat is floated off the carriage, and pursues its passage along the canal. The process of lowering a boat down the incline is the exact converse of that which we have just described.

In our own country a similar contrivance has been employed on the Shropshire Canal, constructed towards the close of the last century. They were here introduced by Mr. William Reynolds. One of these inclines is 600 yards in length, with a perpendicular rise of 126 feet; and another rises 207 feet in a length of 350 yards. The boats, which carry about five tons each, are drawn by machinery

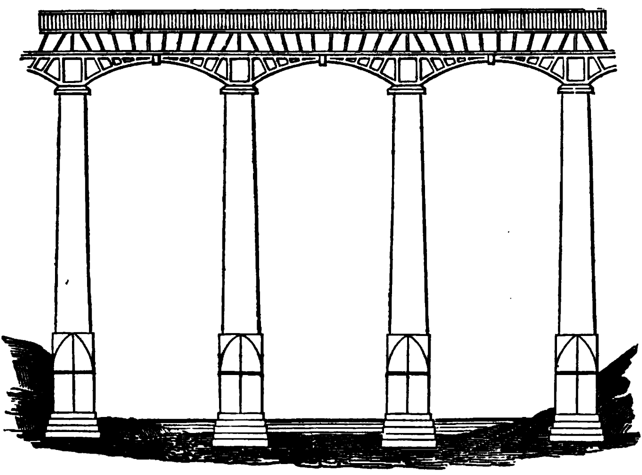
up a railway laid upon these inclined planes, being placed upon carriages formed to receive them, in a similar manner to those in America.

Aqueducts.

In carrying canals across short and deep valleys, in order to avoid a succession of locks which would be required if the surface of the canal were made to conform to that of the valley, it is usual to carry them across at a higher level, through a water-tight channel formed and supported upon arches. Such structures are termed *aqueducts*, and in their construction have afforded some fine opportunities for the display of engineering skill.

Figure 82 is an elevation of a portion of one of

Fig. 82.



the most celebrated aqueducts, that of Pont-y-Cysyllte, constructed by Telford, for the purpose of

Fig. 83.

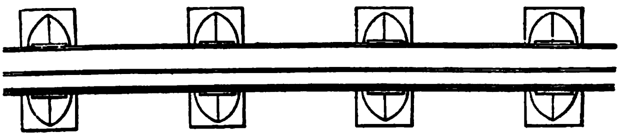
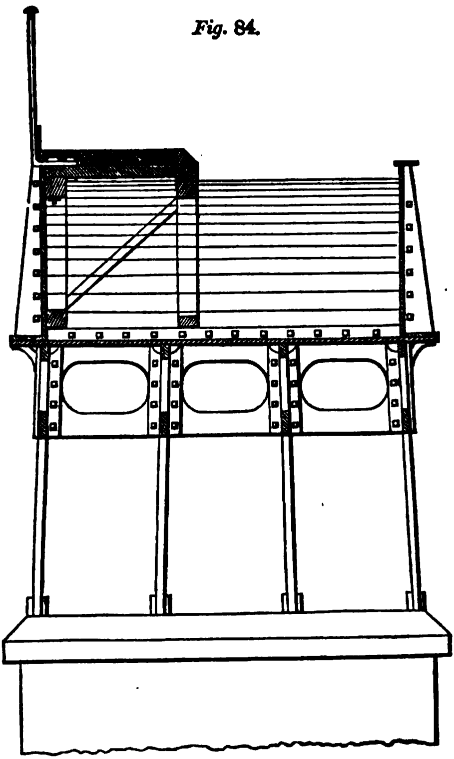


Fig. 84.



carrying the Ellesmere and Chester Canal across the valley of the Dee. It is upwards of 1000 feet in length, consisting of nineteen arches of equal span, but varying in their height above the ground. The three shown in elevation in figure 82, and in plan in figure 83, are the highest, being those which cross the River Dee itself; the surface of the canal is 127 feet above the usual level of the water in the river. The aqueduct itself is a cast-iron trough (shown in section in figure 84), formed of plates with flanges securely bolted together. This trough is supported upon cast-iron arches, each composed of four ribs, supported upon piers of masonry. The towing path overhangs the water, being supported at intervals on timber pillars, as shown in figure 84.

Fig. 85.

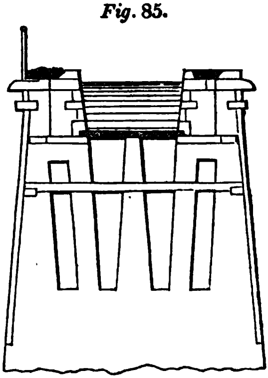


Figure 85 is a transverse section of the Chirk Aqueduct, carrying the same canal across the valley of the Creiroig, at a height of 70 feet above the level of the river beneath. It consists of ten arches of equal span, constructed of masonry; in this case only the bottom or floor of the canal is of iron; the sides, which are 5 feet 6 inches in thickness, being built of ashlar masonry backed with brickwork in cement.

DOCKS.

Different kinds of Docks.

Under the general term *docks* may be included a great number of the different accessaries attached to a port, such as *draw docks*, *dry docks*, *graving docks*, and *floating docks*. It is to the latter of these, however, that the general term docks is usually applied. Draw docks are, usually, nothing more than a sloping road or way leading by a gradual descent from the wharf to the lower level of the shore, and enabling carts and other vehicles to be drawn down on the beach by the side of the vessels lying there, for the purpose of being directly loaded or unloaded without the intervention of boats or barges. This method of discharging and receiving their cargoes is termed beaching, and is very extensively practised by the small class of vessels employed in the coasting trade, which, from their size and build, are enabled to ground (or, as it is technically termed, *take the ground*), without straining or injuring the vessel. The large extent of beach dry at low water, in the River Mersey, opposite Liverpool, called Wallasey Pool, and now forming the site of the entrance basin of the new docks at Birkenhead, was used as a beaching-ground by all the small coasting vessels, and those, the nature of whose trade did not require the superior accommodation afforded by the floating docks.

There is, likewise, a great number of draw docks on the northern bank of the Thames, more particularly between Waterloo and Westminster Bridges.

Graving Docks.

Graving docks (or dry docks) are docks constructed for the reception of vessels while undergoing repairs. They are usually made of such dimensions as to contain only one vessel at a time; their sides are formed in steps, so that the form of the dock is somewhat similar to that of the vessel which it is to contain, but sufficient space is left around it to enable the workmen to get at every part of the bottom of the vessel, and to afford sufficient light for the necessary repairs to be made. The entrance of the dock is closed with gates, precisely similar to those which we have described as belonging to canal locks, by which means, when the vessel has been floated into the dock and the gates closed, the water is pumped out of the dock, leaving it perfectly dry, the vessel being supported on timber struts and shores resting upon the steps already mentioned, as forming the sides of the dock. The accompanying plates are of a very fine graving dock, which is now being constructed by the American Government, at their dock-yard near New York. Figure 86 is a longitudinal section, taken along the center of the dock; figure 87 is a plan; figure 88, a front view of the entrance; figure 89, a transverse section through the center of the dock; and figure 90

Fig. 86.

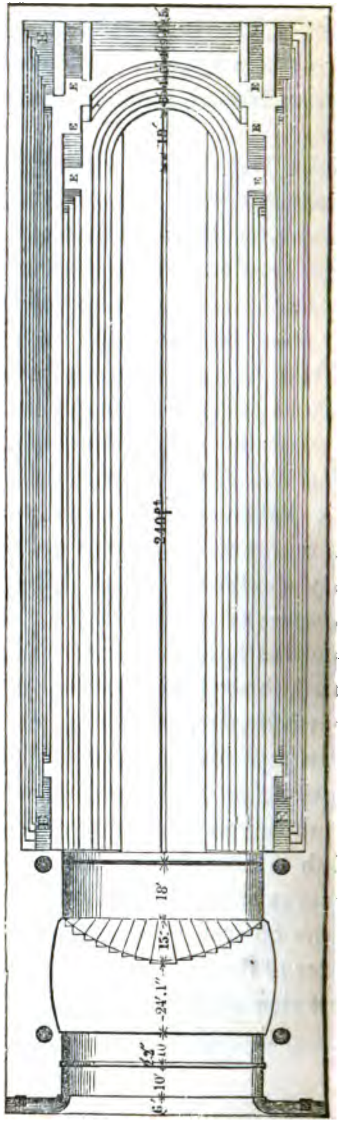


Fig. 87.

Fig. 88.

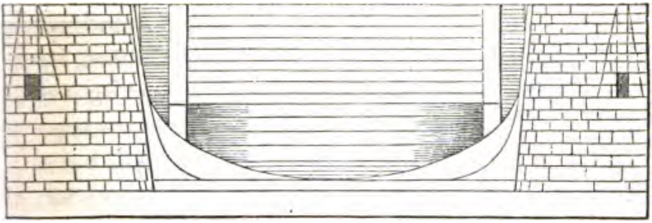


Fig. 89.

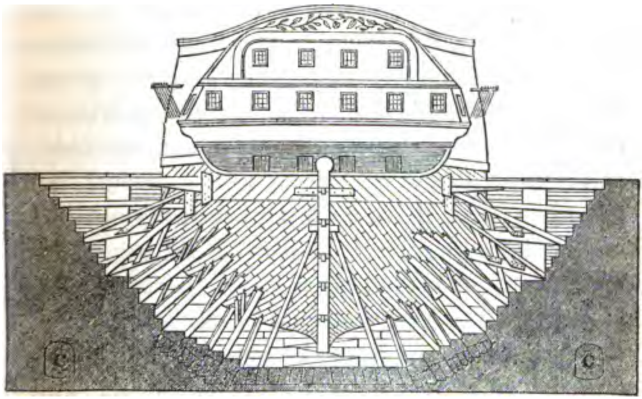


Fig. 90.

another transverse section through the recess for the lock gates. The dimensions of the dock are sufficient to contain the largest vessel in the American Navy, its length within the gates being 320 feet, its breadth 93 feet, and the width of the lock gates 70 feet. The manner in which the vessels are supported upon timber struts, when the water has been withdrawn from the dock, is shown in figure 89, from which it will be seen that ready access is afforded to every part of the vessel. In order that the bottom of the dock may be at all times dry and free from water, it is formed with a slight inclination from A to B (figure 86), and a gutter is carried across the dock at the lower end, leading into a drain or culvert, C C, which passes entirely round the dock, as shown in figures 86 and 89, with a gradual fall towards D; and, the water being constantly pumped out of the culvert, it is impossible for any to accumulate at the bottom of the dock. Several flights of steps (E, E, E,) are provided in different parts of the dock for the use of the workmen, by which they are enabled to reach any part of the vessel with great facility.

Floating Docks.

Floating docks consist of excavations or basins filled with water, the surface of which is always maintained at such a level that the vessels in it are at all times afloat, the dock being separated from the river or sea (as the case may be) by means of

lock gates, so that the fluctuations in the level of the latter, occasioned by the wind and tide, do not affect the former. In most cases, a lock is formed at the entrance of the dock by a double pair of gates, in the same manner as the canal locks which we have already described, by which means vessels can be passed into and out of the docks, even when a considerable difference of level exists between its surface and that of the river without. The sides of the dock are usually formed by walls of masonry, of sufficient strength to resist the pressures of the ground and water to which its opposite sides are exposed. Along the top of the wall, tramways, cranes, and other appliances for readily removing goods from the vessels, are usually placed.

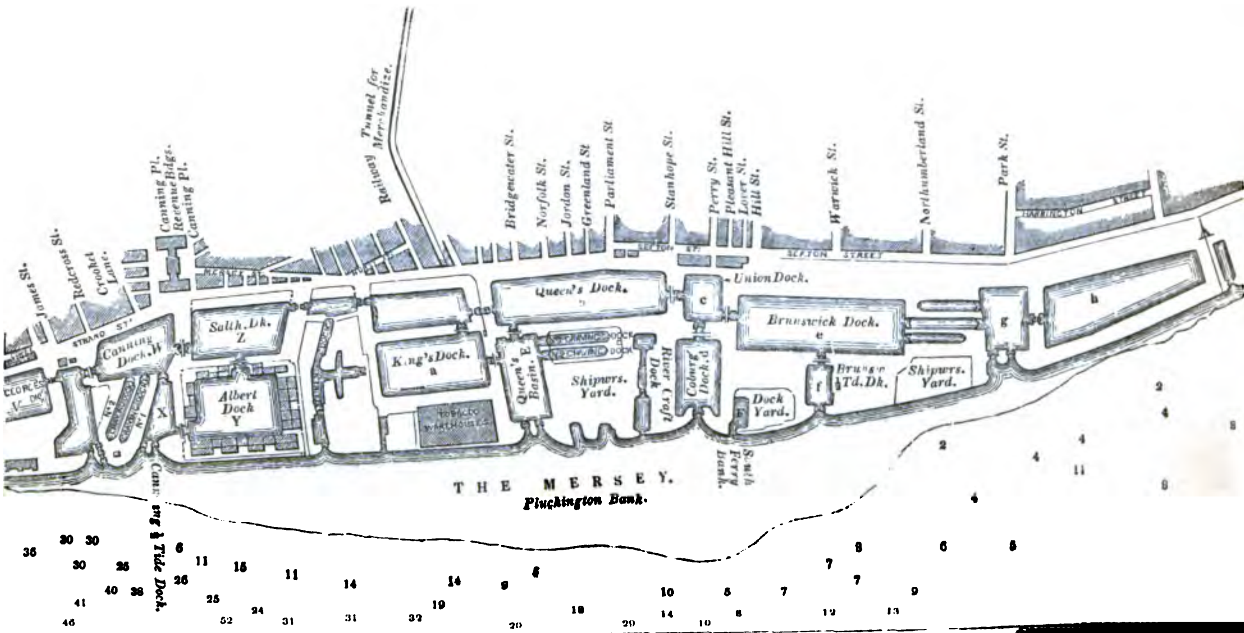
The advantages possessed by floating docks is so great, that few ports of any extent are without them; but it is more particularly, in situations where vessels lying in the natural river or estuary would be much exposed in rough weather, that the benefit of secure and well-sheltered docks is more especially manifest. We have, accordingly, selected the port of Liverpool as affording the best example which we could find, of the successful employment of floating docks; not only on account of the peculiarly-exposed situation of that part of the River Mersey, but because the dock establishments of Liverpool are unequalled throughout the world, both in extent and arrangement.

The situation and relative positions of the various

docks belonging to Liverpool are shown in the plan, figure 91, and the following table exhibits their extent; that is, the area of the water surface in acres of each dock, and the length of quayage possessed by each in yards; as also the width of the entrance in the narrowest part, and the depth of water over the sill of the lock gates at the average level of the high water of spring tides. Those distinguished by an asterisk in the following table are in process of formation. The level of the high water varies considerably, the highest tide on record being six feet nine inches *higher* than the average, and the lowest on record being nine feet *below* the same.

Letters of Reference to Fig. 91.	Name of Dock or Basin.		Width of Entrance.		Depth of Water on Sill at average Spring Tides.		Area of Docks.	Extent of Quay Space.
			ft.	in.	ft.	in.	Acres.	Lineal yards.
	DRY BASINS.							
A	Prince's Basin		....		....		4·320	509
B	Seacombe Basin		....		....		0·373	188
C	George's Basin		....		....		3·382	455
D	George's Ferry Basin		....		....		0·278	160
E	Queen's Basin		....		....		5·040	601
F	South Ferry Basin		....		....		0·605	205
G	*New Dry Basin		200	0	....		6·187	702
	WET DOCKS.							
H	*North Dock, No. 1.	North	60	0	25	0	3·443	406
		South	50	0	25	0		
I	* ,, ,, No. 2.		60	0	24	3	5·050	558
J	* ,, ,, No. 3.		51	0	23	9	7·026	753
K	* ,, ,, No. 4.		60	0	24	3	7·989	803
L	* ,, ,, No. 5.	North	45	0	24	3	9·642	935
		South	45	0	24	3		
M	* ,, ,, No. 6.		60	0	24	3	7·851	820
N	* ,, ,, No. 7.	East	60	0	24	9	3·168	400
		West	60	0	24	9		
O	* ,, ,, No. 8.		65	0	24	9	10·021	867
P	Clarence Dock		47	0	21	5	5·767	740
Q	Clarence Half Tide Basin		50	0	23	9	3·930	635
R	Trafalgar Dock		45	0	23	9	5·884	727
S	Victoria Dock	North	45	0	23	2	5·625	681
		South	40	0	23	2		
T	Waterloo Dock		45	0	24	8	5·577	700
U	Prince's Dock	North	45	0	24	2	11·127	1187
		South	44	11$\frac{3}{4}$	24	2		
V	George's Dock	North	41	11$\frac{3}{4}$	22	9	5·032	645
		South	40	1	22	9		
W	Canning Dock		45	0	24	6	4·078	585
X	Canning Half Tide Basin		45	0	24	7	2·555	429
Y	Albert Dock		45	0	24	7	7·616	812
Z	Salthouse Dock (North and West)		45	0	24	3	4·655	656
a	King's Dock		42	0$\frac{1}{2}$	23	3	7·693	800
b	Queen's Dock	North	42	0$\frac{1}{2}$	20	0	10·383	1082
		South	41	11$\frac{1}{2}$	21	5		
c	Union Dock		42	0	20	0$\frac{1}{2}$	2·591	407
d	Coburg Dock		70	1	23	3	4·265	650
e	Brunswick Dock		42	0	22	9	12·438	1005
f	Brunswick Half Tide Dock	West	45	0	24	3	1·428	318
		East	42	0	23	9		
g	*South Dock, No. 1.	North	40	0	23	3	3·464	446
		South	50	0	23	3		
h	* ,, ,, No. 2.		45	0	23	3	11·219	1148

Fig. 91.—PLAN OF THE LIVERPOOL DOCKS.



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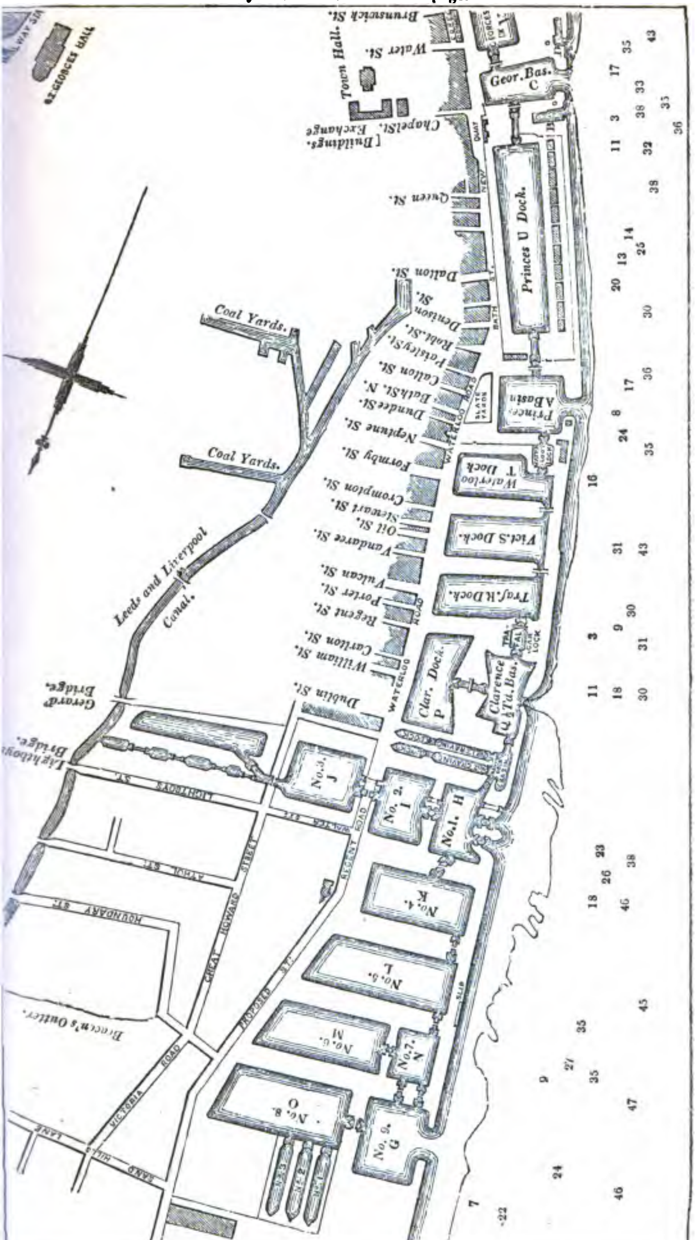


By a reference to the plan (figure 91), it will be seen that, while most of the docks have a separate entrance from the Mersey, they likewise communicate with each other, forming an almost unbroken chain; so that barges and other craft may pass from one dock to another without the necessity of being locked out into the river, and back again into the docks. They also communicate, by a series of locks, with the Leeds and Liverpool Canal, so as to allow barges from the manufacturing districts to reach any of the docks without passing into the Mersey.

Some idea of the extent of this truly magnificent Dock Establishment may be formed from the following statement of their dimensions. The extreme length of the river wall belonging to the dock estate is very nearly 4 miles; and the total area of water surface 195 acres, including 20 acres of basins and 5 acres occupied by locks and passages; the whole extent of quays for loading and unloading is upwards of 14 miles, including 1 mile 1060 yards belonging to the basins, and 1 mile 989 yards to the locks and passages. In addition to which, there are not less than eleven graving docks, similar to that described at page 95, either completed or in progress, the aggregate length of which will be 1825 yards, or upwards of a mile.

The total area of water surface afforded by the floating docks of the port of London is about 227 acres, of which 154 acres is on the city or Middlesex side, and the remainder on the Surrey side

of the Thames. The names of the docks on the Middlesex side, the date of their being opened for the purposes of trade, their area, and the name of the engineer by whom they were constructed, are shown in the following table:—

Name of Dock.	Area in Acres.	Date of Opening.	Engineer.
West India Docks . .	82	1802	Jessop and Rennie.
East India Docks . .	31	1803	Ralph Walker and Rennie.
London Docks . . .	30	1805	Rennie.
St. Katharine's Dock .	11	1828	Telford.

It might at first sight excite surprise, that the dock accommodation of the port of London is so nearly the same as that of Liverpool, although the number of vessels belonging to the latter port is not more than one-third of those belonging to the former. But it should be remembered, that from the exposed situation of the Mersey, off Liverpool, and the strong stream caused in the river by its sudden contraction, vessels cannot lay with safety or ease in the river, and therefore the docks of Liverpool are required to be of sufficient extent to accommodate the whole trade of the port. Whereas, in the case of the port of London, the fine reaches of the Thames afford a secure and convenient berth for an enormous number of vessels; the colliers, coasting vessels and steam vessels being entirely thus accommodated, and the docks being principally used by the larger vessels connected with foreign

trade. These smaller vessels are disposed in *tiers*, on each side of the river, moorings being laid down for their use; and the number of vessels in each tier is so regulated by the Harbour Masters of the port, as to leave at all times a clear navigable channel between them, not less than 300 feet in width. The number of vessels which can be thus accommodated is 461, of which 244 are on the south side, and 217 on the north side of the river.

In the port of London, and in most situations, the docks are formed by *excavations* made on the banks of the river, but at Liverpool they have been formed in the river itself, by inclosing within walls of masonry a portion of the beach of the Mersey, and afterwards excavating the bottom of the docks thus reclaimed, as it were, from the river, to a uniform and sufficient depth. In some other situations, as at Bristol, the natural river flowing through the city has been converted into a floating dock, by placing lock gates across it, both above and below the city, and forming a new cut or channel for the waters of the old river to pass along, and for the use of vessels having to proceed further up the river.

The lock entrances of docks are precisely similar in principle to those already described as being used on canals; but, as their dimensions are usually much greater, some difficulty has been experienced in obtaining timber of sufficient size for their construction: on which account, and for greater durability, iron lock gates have been employed in some situations.

The strength of the dock walls, and their sufficiency to sustain the pressures to which they are exposed (being that of the ground on one side and of the water on the other), may be determined by means of the rules already given*.

BRIDGES.

Selection of Site, and determination of the kind of Bridge.

A great variety of circumstances require to be considered in determining the best position, proportions, and materials, of which to construct a bridge for any particular situation. The most general and important object to be attained is the establishment of a convenient and permanent means of communication between the two opposite shores, with as slight an interference with the free navigation through the bridge as possible; and the attainment of this object is, in many situations, attended with considerable difficulty, inasmuch as the conditions requisite for the preservation of the navigation are incompatible with those required for the formation of a convenient road. For example, in the case of a river with low banks and much frequented by shipping, the construction of a bridge which would at the same time afford an uninterrupted passage for vessels under it, and a convenient means of transit for vehicles over it, would be almost impossible; because, were the arches of the bridge

* Rudiments of Engineering, Part I., pages 66–70.

made of sufficient height to allow vessels freely to pass through them, the level of the roadway would be so much elevated above that of the adjoining banks as to require either a very steep approach from both sides, or long and expensive embankments; and if, on the other hand, the level of the roadway were so low as to remove these objections, the passage of vessels with masts would be stopped, and the navigation materially interfered with.

To remove these difficulties in such a situation, it has been suggested to construct the bridge with one or two of its arches so arranged as to be capable of being opened, at intervals, for the passage of vessels. But such an arrangement only mitigates the evil, and is far from entirely removing it; and, in those situations where the traffic over the bridge was considerable and continuous, the periodical stoppages occasioned by the opening of the passages for the navigation would be extremely inconvenient.

The preservation of a free channel for the navigation, and the formation of a convenient means of communication, are, however, not the only important points to be considered. The effect which the construction of the bridge is likely to produce upon the river itself, whether it would tend to increase the velocity of the stream, and so produce a scour and washing away of the sides and bed of the river, and ultimately, perhaps, endangering its own existence; whether it would alter, and in what manner, and to what extent, the existing direction of the current, and

so cause the formation of eddies and still water, and their constant attendants, shoals and banks of deposit; or whether the obstruction of its piers might not, in times of floods, by damming back the water, occasion the overflow of tracts of country adjoining the river above the site of the bridge, are all inquiries of immense importance, which require to be duly weighed and considered previous to determining the proportions which ought to be given to the several parts of the structure.

There are three different kinds of bridges, namely, those of masonry, those of iron or timber, and those on the suspension principle, each of which is peculiarly adapted for certain situations and circumstances; and, therefore, the *kind* of bridge to be adopted is also a point to be considered in the first stage of the investigation, although there are certain situations for which one kind of bridge would be as well suited as another: in which cases the choice becomes merely one of taste, or is determined by pecuniary considerations.

With regard to the selection of the best site for a bridge, in many cases very little room is left for the exercise of the Engineer's judgment in the matter, the position of the bridge being determined by other circumstances, such as the necessity of joining two existing roads, or of avoiding interference with existing establishments on the river's banks. Where, however, the choice of its position is left with the Engineer, it becomes necessary for him to

make a careful personal inspection of the locality, to have the banks of the river accurately surveyed, as well as soundings taken of the depth of the river at uniform distances apart, and borings of the nature of the strata composing its bed. In addition to which, he should inform himself of the velocity of the stream, the height of the water, and the quantity passing down the river at all times and seasons of the year, as well as the nature and extent of the trade carried on upon it. Prepared with these data, he will be in a position properly to consider the subject, and to arrive at correct conclusions. In the infinite number of different cases and varying circumstances which may arise in practice, it would be impossible to lay down any general laws upon this subject, but the following hints will be found of service in guiding to a correct determination. That part of the river should be selected whose course is straightest, bends and sharp turns being very unsuitable situations for a bridge, because at such parts the stream is usually irregular, and not parallel to the river's banks; and unless the piers of the bridge were placed parallel to the direction of the stream, which in such a situation they could hardly be, they would offer a much greater obstruction to the motion of the water, occasion eddies and shoals below the bridge, be liable to be undermined by the action of the stream acting only on one side of the pier, and endanger the safety of vessels navigating the river by their tendency to be carried against the

piers. For the same reasons, the bridge, if possible, should cross the river at right angles to the course of the stream, and, if this be prevented by circumstances, the piers must still be placed parallel to the stream, and making an angle with the direction of the bridge. An arch so constructed is termed a *skew* arch, and the angle formed by the sides of the piers and a line perpendicular to the direction of the bridge is termed the angle of skew, and should not exceed seventy degrees. Not only must the Engineer, however, be careful to construct his piers in such a manner as not to alter the *direction* of the stream, he must also see that its *velocity* is not materially increased, which, if the bed of the river is of a soft or loose nature, would cause it to be rapidly scoured away, and, by undermining the foundations of the bridge, in time endanger its stability. The following Table, taken from the "Edinburgh Encyclopædia," exhibits the velocity of stream, which, under ordinary circumstances, the various descriptions of soil enumerated are capable of resisting.

The ordinary nature of Current.	Velocity. In feet per Second.	Velocity. In miles per Hour.	Materials that resist these velocities, and yield to more powerful ones.
Very slow	0·25	0·171	Wet ground, mud.
Gliding	0·50	0·341	Soft clay.
Gentle	1·00	0·682	Sand.
Regular	2·00	1·364	Gravel.
Ordinary velocity	3·00	2·046	Stony.
Extraordinary & rapid floods	3·35	2·284	Broken stones, flints.
Extraordinary floods and	3·45	2·352	Collected pebbles, soft schistes.
rapids	3·55	2·420	Beds of Rocks.
Torrents and Cataracts	9·86	6·723	Hardened rocks.

It should, however, be observed, that the scouring

influence of rivers depends not only on the *velocity* with which they move, but also upon the *depth* or *weight* of water resting upon their bed. The reason of this will be readily understood if we consider that the water acts upon the materials composing the bed of the river by its *friction* very much in the same manner as a solid body would; and it therefore follows that, the more heavily the water is pressed against the ground, the greater will be its friction, and the more powerful its scouring agency; in addition to which, when the depth is considerable, the increased pressure of the water causes it the more readily to insinuate itself into the interstices of the strata, which it thus loosens and assists in breaking up. It is, however, only in the first act of breaking up the bed of the river that an increase of the depth of water influences and increases its scouring effect; the power of the water to carry or roll onward the matters which it has torn up depends only upon its velocity, always supposing that the quantity of the water is such, that its momentum is not influenced by the resistance of these matters, and that the depths are within such limits that the specific gravity of the water is not materially increased by compression.

The most important point claiming the attention of the Engineer, as far as the stability of the bridge is concerned, is to obtain a secure and unyielding foundation for the piers, and abutments, such as will safely support the superincumbent weight of the

bridge and its load, and is not likely to be affected or disturbed by changes in the bed of the river, or other circumstances.

It may here be generally observed, that while bridges of masonry are best adapted for the support and conveyance of heavy and continuous traffic, such as that passing daily over London Bridge, they offer greater obstruction both to the stream and navigation than either iron or suspension bridges, on account of the *comparative* smallness in the span of their arches, and the piers occupying a space varying, in the examples which we have given in the tables following*, from $\frac{1}{3\cdot66}$th or $\frac{3}{11}$ths of the span, as in the bridge of the Holy Trinity at Florence, to $\frac{1}{9\cdot26}$th or $\frac{4}{37}$ths, as in the Neuilly Bridge over the Seine; while those of the iron bridges vary from $\frac{1}{7\cdot8}$th or $\frac{5}{39}$ths, as in Vauxhall Bridge, to $\frac{1}{14\cdot4}$th or $\frac{5}{72}$nds, as in the Pont du Carrousel; and those of the suspension bridges from $\frac{1}{8\cdot3}$th or $\frac{5}{44}$ths, as in the Brighton Chain Pier to $\frac{1}{43\cdot5}$th or $\frac{2}{87}$ths, as in the bridge near Fribourg. These numbers may be taken as those representing the comparative obstruction which the respective bridges offer to the stream; but that which affects the navigation depends not only upon the width or span, but also on the height or headway afforded under the arch of the bridge, so that we should, as far as the facilities which each offers to the navigation, rather compare the area of the space between the intrados of the arch and

* See Tables pages 117, 140, and 147.

the surface of the water; and this we have done in the following Table, taking as an example of bridges of masonry, London Bridge; of iron, Southwark Bridge; and of suspension bridges, that across the Thames, near Charing Cross. There is another point, in respect of which the suspension bridges and those of iron are preferable to those of masonry, and this is their much smaller weight, a point which we have illustrated by a comparison of the weight of the center arches and piers of the three bridges above-mentioned. Although, however, with these advantages, they may be also considered as much less costly, there are certain situations in which undoubted preference should be given to bridges of masonry. Such are those in which the traffic is continuous and heavy, or the site much exposed to hurricanes and tempests, in either of which case a suspension bridge would not be advisable, as would not an iron bridge in the former.

Name of Bridge.	Distance between centers of Piers.	Span of center Arch.	Thickness of the Piers, the span of the Arch being unity.	Weight upon base of center Pier. Of the Pier itself.	Weight upon base of center Pier. Of the Superstructure.	Average Weight of the Superstructure, for 1 foot in length and 1 foot in width.	Thickness from Soffit to Roadway, at the Crown. Ft.	Thickness from Soffit to Roadway, at the Crown. In.	Arcs of clear space between the intrados of the Arch and high water; the greatest headway multiplied by the span being unity.
	Feet.	Feet.		Tons.	Tons.	Tons.	Ft.	In.	
London Bridge......	176	152	·158	6830	14615	1·800	8	2	·7854
Southwark Bridge ..	264	240	·100	6580	3080	·314	8	0	·7173
Charing Cross Bridge	676½	646	·047	5140	535	·061	1	9	·9340

Of Bridges of Masonry.

Having already stated, at some length, the principles upon which the equilibrium of arches of masonry depend, and given rules for finding the pressure upon the keystone*, by which its depth should be determined; and that being fixed, for so proportioning the depth of the other parts of the arch, that the whole may be in equilibrium†, it only remains here to offer a few remarks upon the practical use of these rules. By reference to the Table there given‡, it will be seen how widely the practice of engineers differs with regard to the load which they consider it safe to place upon an arch of masonry. Taking into consideration the materials of which it is composed, the bridge which carries the Great Western Railway across the Thames, near Maidenhead, is certainly the boldest which has ever been constructed, the actual pressure at the crown of the arch being about one-third of that which would begin to injure the cohesive strength of the material of which it is composed. And, although the construction of this bridge has shown that it is practicable to approach much closer to the load which would cause failure than had before been considered safe, it is questionable how far prudence would warrant such an approach in ordinary cases, especially when we consider how many accidental

* Rudiments of Engineering, Part I., page 51.

† Ibid., page 46. ‡ Ibid., foot note, page 52.

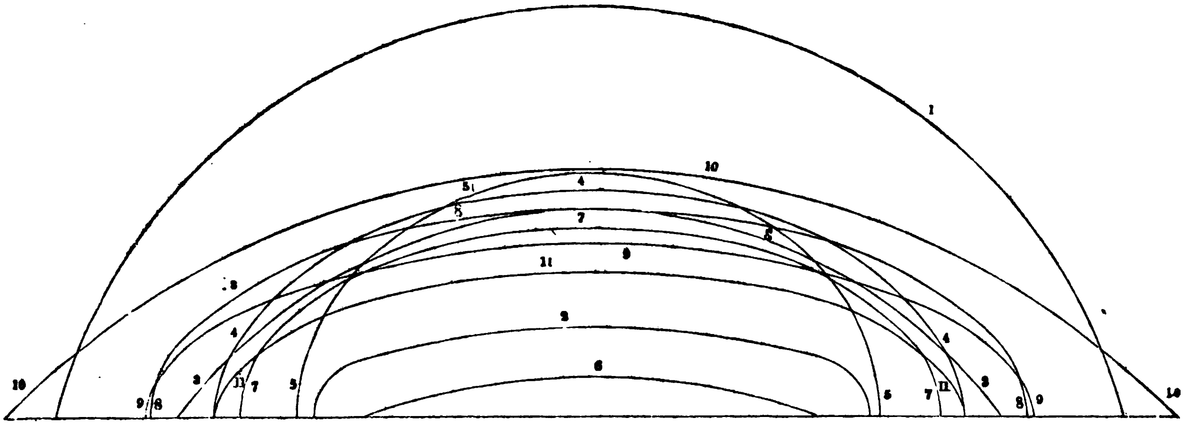
circumstances may deteriorate the stability of the arch, to guard against which it seems desirable that a much wider margin should usually be given, and that the greatest load upon the key-stone should not be greater than $\frac{1}{20}$th of that which would *begin* to crush its material in bridges exposed to only ordinary traffic, and in those which are continually exposed to the tremour and vibration occasioned by a continuous and very heavy traffic, not more than $\frac{1}{30}$th.

We have in the annexed Table exhibited the proportions and dimensions of some of the principal bridges in Europe, in which we have given the radius of curvature of the main arch at its soffit, as well as the depth of their key-stones, and the materials of which they are composed, from which the student will be enabled to observe the proportions which have been adopted by some of the most eminent engineers.

Table of the Dimensions of some of the Principal Bridges of Masonry.

Nos. of reference to figure 92.	Name and Situation of Bridge.	Number of Arches.	Clear Waterway.	Total length, including Piers.	Width of Bridge between Parapets.		Form of the center arch.	Dimensions of Center Arch.					Material.	Date of Completion.	Architect or Engineer.
								Span.	Rise or Versine.	Radius of Curvature at the Crown.	Depth of the Key-stone.	Thickness of the Piers.			
			Feet.	Feet.	Ft.	In.		Feet.	Feet.	Feet.	Feet.	Feet.			
1	Vieille-Brionde, over the Allier	1	183¼	..	16	0	Circular	183·25	70·25	94·87	5·25	..	Tufa	1454	Grenier and Estone.
2	Bridge of the Holy Trinity, over the Arno at Florence	3	270¼	322½	33	9	Slightly Pointed	95·25	14·83	172·63	2·75	26	White Marble	1569	B. Ammannati.
3	Pont-y-Prydd, over the Taaf.	1	140	..	..		Circular	140	35	87·5	2·5	..	Sandstone	1755	Edwards.
4	Bridge of Mantes, over the Seine	3	358	409	35	5	False Ellipse	127·83	38·25	134·6	6·25	25·53	Saillancourt Stone	1765	Perronet and Kupeau.
5	Blackfriars Bridge, over the Thames	9	780	926	42	0	Idem	100	41·5	56	6·58	20	Portland Stone	1771	Mylne.
	Neuilly Bridge, over the Seine	5	639	766	48	0	Idem	127·83	31·83	260	5·25	13·83	Saillancourt Stone	1774	Perronet.
6	Bridge of St. Maxence, over the Oise	3	230	249	41	6	Circular	76·67	6·25	121	4·67	9·5	..	1784	Idem.
7	Waterloo Bridge, over the Thames	9	1080	1240	41	6	Ellipse	120	32	112·5	5·0	20	Granite	1816	Rennie.
8	Gloucester Bridge, over the Severn	1	150	..	35	0	Idem	150	35	160	4·5	..	Sandstone	1827	Telford.
9	London Bridge, over the Thames	5	692	784	53	6	Idem	152	29·5	162	4·75	24	Granite	1831	Rennie.
10	Bridge over the Dee, at Chester	1	200	..	33	0	Circular	200	42	140	4·0	..	Sandstone	1833	Hartley.
11	Bridge carrying the Great Western Railway across the Thames, at Maidenhead	2	256	284	28	0	Ellipse slightly Pointed	128	24·25	169	5·25	28	Bricks laid in Cement	1835	Brunel.

Fig. 92.



In the accompanying plate, figure 92, we have shown the intradoses or profiles of the principal arch of each of the bridges mentioned in the foregoing table, all drawn to the same scale, so as to afford at one view a comparison of their relative size and form.

In the construction of a bridge the most important point is to obtain an unyielding foundation for the piers and abutments, and, if this can be secured, the engineer may with safety adopt bold proportions for the arches of his bridge; but, in a situation in which the piers would be likely to settle to any extent, every precaution should be taken to increase the stability of the arches. It is a matter which may reasonably excite surprise, that engineers should so universally construct the piers of their bridges with solid masonry, since a very little consideration would suffice to show, that such a mode of construction is usually the worst which could be adopted, especially where the ground beneath the piers is of a yielding nature. The real office which the pier of an arch is intended to perform is merely to support the arch, to receive its weight and transmit it to the foundation, and it performs this in the most perfect manner when it adds to that weight in the least degree; in most cases, however, the weight of the pier itself is equal to about half that of the superincumbent arch*, so

* By reference to the table at page 114, it will be seen that the weight of that portion of the pier of London Bridge *below* the spring-

that the weight which the foundations have to carry is half as much again as the real weight of the bridge. In the construction of the piers of a bridge, the points which ought to be attended to are as follows; namely, that the substance of the pier shall be sufficient to enable it to sustain without injury the vertical pressure of the arch and its load, as well as that of the water and any accidental force to which it might, under extraordinary circumstances, be liable to be exposed; and that its base should be of such dimensions, that the pressure arising from its own weight, and that which is insistent upon it, may be distributed over a sufficiently large area of ground. Now, so long as these two conditions are fulfilled, it is sufficient; and any additional substance given to the pier is clearly so much additional load thrown upon the foundations, and is positively detrimental to the stability and security of the structure.

Perronet appears to have understood better the real use of piers, although he seems to have been more disposed to lighten them by reducing their external dimensions, rather than by constructing them hollow; for instance, in the Neuilly Bridge already mentioned, we find the piers are less than one-ninth of the span of the arch. In the bridge of St. Maxence he has, however, effected the same

ing is nearly equal to half that of the center arch; and that, in the case of Southwark Bridge, the weight of the pier is more than twice as great as that of the superstructure, which it merely serves to support.

object by carrying up the piers in four columns united in pairs, and turning a small arch across between them intersecting the main arch of the bridge, as shown in figures 93 and 94.

Fig. 93.

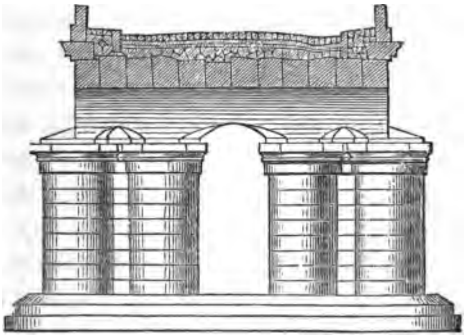
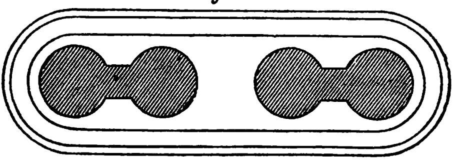


Fig. 94.



The best examples, however, of a judiciously-contrived pier, are those of the Charing Cross suspension bridge, lately constructed from the designs of Mr. I. K. Brunel, and the construction of which is fully shown in figures 106, 107, 108, and 109 *. Here the weight of that portion of the pier which is below the rusticated basement is only two-thirds of what it would have been had it been built solid, as most of the other bridges across the Thames have been.

* Rudiments of Civil Engineering, vol. iii.

The foregoing remarks apply with equal force in the case of abutments as in that of piers, the usual practice in the construction of which has been to form a solid mass of masonry, the weight of which materially *assists* the thrust of the arch in producing settlement by the compression of the ground upon which it rests. It is obvious that the real use of an abutment to an arch is nothing more than to extend the surface upon which it rests and from which it derives support, without, at the same time, materially increasing its pressure, and so, by reducing the load, on any given area, to increase the stability of the structure; whereas, it would be found in the majority of cases, that the pressure upon every square foot of surface at the springing *is less than* that which the thrust of the arch and the additional weight of the abutment together occasion on the foundation upon which they rest.

In building a structure, the weight of which is considerable, upon any kind of substratum (excepting only rock), some amount of sinking or settlement from the compression of the ground will almost always be found to take place, and, as it is very desirable, in the case of a bridge, that the settlement of the piers and abutments, if any, should take place previous to the construction of the arch, the piers and abutments, when built up to the springing course, should be loaded with a weight at least equal to that of the arch which they are afterwards to carry; and in this state they should be left, if possible, for some

months, during which period the water should be admitted into the interior of the coffer dams, so that the piers may be brought as nearly as possible into the same condition as that in which they would be when the bridge was completed; so that, if the ground is disposed to yield under the joint influence of the water and the load, it may do so before the construction of the arches is commenced.

Previous to the piers being loaded, and at regular intervals afterwards, careful levels should be taken to ascertain whether any settlement has occurred; and as soon as it has been found by means of these observations that all subsidence has ceased, and not until then, the arches should be commenced. The loading of the piers should be gradually removed as the arches progress, in such a manner that the weight upon the piers may be maintained as nearly uniform as possible.

Next in importance to securing a firm foundation for the piers and abutments is the proper construction of the arch itself. Could the arch-stones or voussoirs be worked with perfect accuracy to the wedge form required, and then be brought into immediate contact without the interposition of any mortar or cement, as was frequently done by the Romans and the Cyclopæan builders of old, we should have an arch in the highest perfection, not liable to settlement, and which would maintain its form unaltered as long as the materials of the stone endured. Although, however, we cannot in practice dispense entirely with

mortar between the joints, they may be reduced so much in thickness as to leave but small room for any after-settlement in the arch arising from their compression; and, by proper attention to these points, engineers have so far succeeded as to be able to construct arches of two hundred feet span, with a settlement in the crown of the arch of scarcely 2½ inches.

To support the voussoirs of the arch during its construction and until the insertion of the key-stone, it is requisite to have a timber platform termed the *center* or *centering*, the upper surface of which is made to correspond accurately with the intrados of the arch, so that the stones being placed upon it may be retained in their proper position, until the arch is completed by the insertion of the key-stone.

It is requisite that the center of an arch, of any size, should be constructed with the greatest possible care, and in such a manner that the weight of the arch-stones may not alter its form; a point very difficult to be secured with a material so elastic as timber, and where the load is at first thrown only on a small portion of the framing. In cases where this has not been sufficiently attended to, it has been found requisite to place a load upon the middle of the centers, to counteract their tendency to rise at that point, occasioned by the depression of their haunches under the weight of the arch-stones. And in the centers for the Neuilly Bridge, designed by Perronet, from their peculiar mode of construction,

the settlement was so considerable (nearly two feet at the crown) that a variety of expedients had to be resorted to, to prevent their being crushed, and letting down the arches. It is also requisite in the center of an arch to have the means of gradually lowering the center as soon after the completion of the arch as may be deemed prudent, which should be done in the most regular and gradual manner, in order that the arch may have time to settle equally; this operation is technically termed *striking* the centers, because they are usually supported on wedges, the striking out of which allows of its gradual descent, in the manner which we have described.

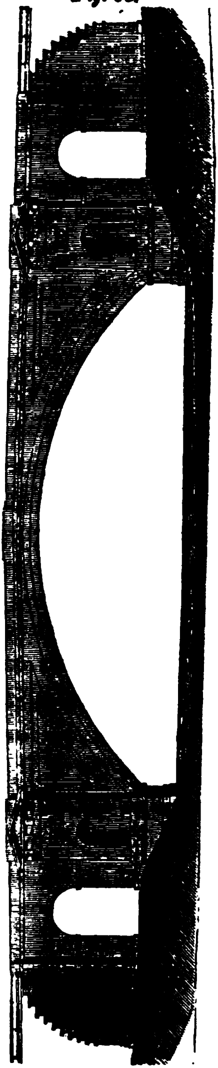
As an illustration of the practical operations involved in the construction of a stone bridge, we have selected the Grosvenor Bridge over the Dee at Chester, not only on account of the boldness of the arch, but also because several novel expedients were adopted by its engineer, Mr. Hartley, of Liverpool, with very great success. The profile of the arch is shown by the line 10 in figure 92, and the principal dimensions of the bridge will be found in the table at page 117. Figure 95 is an elevation of the bridge, and figure 96 a longitudinal section of half the arch and the north abutment, showing the center upon which it was constructed.

The south abutment of the arch is founded upon the solid rock, as is also the principal portion of that on the north side; but the rock suddenly terminating at A, and being succeeded by a stratum of very loose

sand, it was found necessary to drive piles for the support of the back portion of the abutment, as shown in the figure. The material of which the bridge is constructed is the native sandstone, with the exception of the face of the abutments and the two first courses of the arch, which are of granite, and the three center courses of the arch and the quoins, which are of Anglesea marble or limestone. By an inspection of the plate it will be seen that the principle of the arch is carried out in the abutments, the courses of which are made to radiate towards the center of the intrados of the bridge, until they meet the rock, in which steps were cut, the bed of which partook of the same slope, so that the rock itself may be regarded as the actual abutment of the arch.

Upon striking the centers of bridges, it is usually found that, in consequence of the compression in a greater or less degree of the mortar in the joints of the voussoirs, the form of the arch becomes modified,

Fig. 95.



on account of the greater settlement of the stones in the center or crown of the arch. The reason of which is, that as the stones approach the haunches they become less inclined to the horizon, and a greater portion of their weight is thrown upon the joint, less being borne by the center, from which cause the compression of the joints near the haunches takes place during the construction of the bridge; whereas, in those stones which are near the crown of the arch, their weight being almost entirely borne by the centers, the joints are but slightly compressed until the weight of the stones is brought upon them by the operation of striking the centers, and then the settlement consequent upon this compression takes place. We have already explained*, while treating of the stability of arches, that, when the crown of an arch sinks, the tendency of the arch-stones near the crown is to turn upon their outer edges, and of those near the haunches upon their inner edges, in the manner shown in figure 23, the effect of which is frequently seen in the opening of the joints at the back of the arch at the haunches, and on the soffit of the arch near the crown, pieces being frequently splintered off from the opposite edges of the joints in consequence of this tendency to turn about them.

Now in the Chester Bridge this tendency of the joints to open was guarded against by the insertion of thin plates of lead between the arch-stones on each

* Rudiments of Civil Engineering, Part I., page 49.

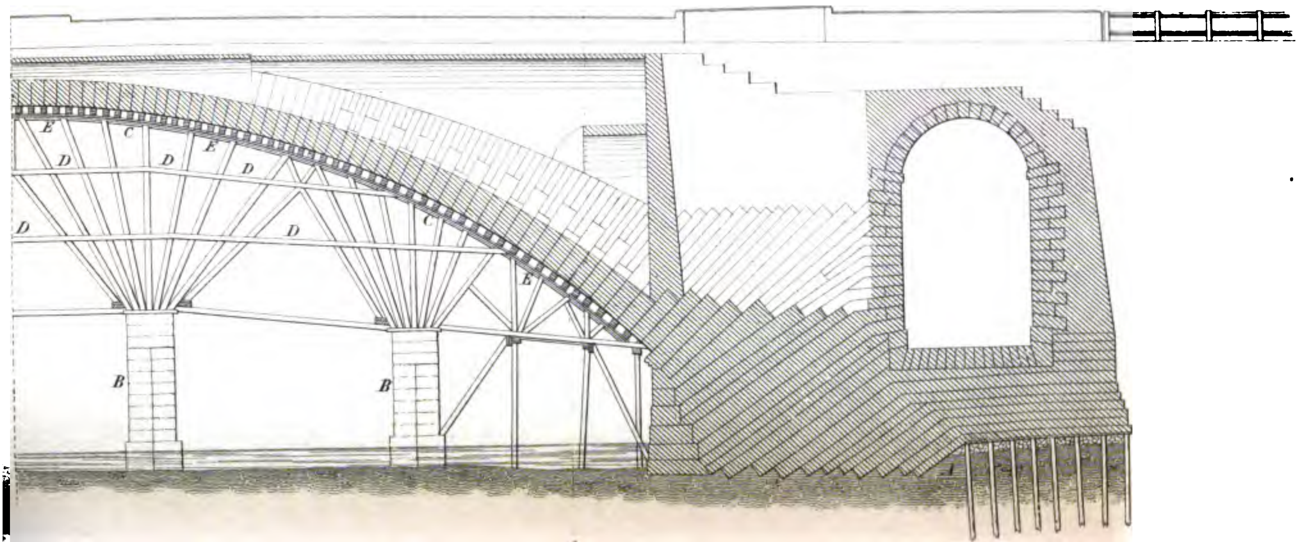
side, from the springing up as far as that point in the arch, where the line of pressure passes through the center of the stones, which in this case was assumed to be at about one-third of the arch; and further, by two wedges of lead being laid under the springing course, which were an inch and a half in thickness on the face of the arch, and ran out to nothing at the back. By these means, as the arch settled, the lead, being of a yielding nature, became slightly compressed, and caused the pressure to be more equally distributed over the surface of the joints. The following method was also adopted of setting the key-stones, by which the joints near the crown of the arch were somewhat compressed previous to the centers being struck: three thin strips of lead were placed on the sides of each of the stones composing the last course on each side of the key-stones, which latter, having been besmeared with a thin kind of putty composed of white lead and oil, were forced down into their places by a small pile-driving engine, the strips of lead serving as slides to prevent the stones rubbing against each other.

We have yet to describe the center, which was designed by Mr. Trubshaw, the contractor for the bridge, and differed very materially from any which had been previously constructed. It was supported upon four temporary piers of stone, built in the river, two of which are shown at B, B, in the section (fig. 96). From the tops of these piers the timbers which were intended to support the arch-stones radiated in the

FIG. 96.

CHESTER BRIDGE.

B



HALF SECTION SHEWING THE CENTRING

manner shown in the drawing, their lower end being secured in a cast-iron shoe fixed on the pier for their reception, and their upper ends being connected together and retained at nearly equal distances apart by two thicknesses of planks C, C, bent round to the form of the arch; and they were still further secured by the horizontal timbers, D, D, to which they were bolted. There were six of each of these fan-like framings in the width of the bridge, placed at equal distances apart, and steadied by transverse timbers. The timbers, E, E, E, for the support of the arch-stones, technically called *laggings* (one of which was placed under every joint), were supported upon the curved rim C, C, of each of the framings; folding wedges being placed under them, so that, by driving the wedges back, any portion of the arch might be gradually lowered at pleasure. The peculiarity in the construction of this center consisted principally in the timbers being disposed radially, so as to receive the pressure of the voussoirs in the direction of their length, after the manner of a pillar, in which direction timber, when subjected even to very considerable strains, suffers very slight compression; and these centers were not therefore liable to the failing of too many others, that of change of form, under the unequally-distributed load of the arch while in course of construction. The manner in which the centers were struck was also peculiar, that of having separated wedges under each arch-stone, so that any portion of the arch might be relieved

from support, while the remainder was still borne by the center; and thus the engineer possessed the power of allowing those parts of the arch to settle first which he might think desirable. Whereas in the ordinary form of center it is usual to have the entire span of the arch in one framing supported upon wedges at each extremity, upon striking which the whole of the center would be lowered simultaneously*.

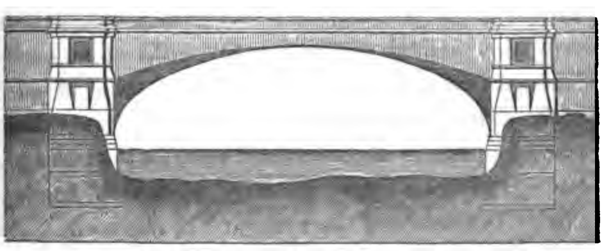
The method which we have above described, of inserting strips of lead between the joints of the voussoirs, was adopted with the same object in the construction of a bridge over the Dora Riparia, near Turin. In this instance the engineer constructed the center with a greater rise than that which he intended the arch to have when completed, so as to allow for its settlement; the span of the arch was 147·64 feet, and the versine or rise 18·04 feet, while that of the centers was made equal to 18·9, or about 10 inches greater. The arch-stones, which were of granite, having been accurately formed to the proper wedge-form, were then put in their places on the center, in such a manner that the joints near the haunches were made wider on the face of the arch than at the back, those midway being made parallel, and those near the crown wider at the back than on the face of the arch, no mortar

* For a further description of this bridge, and plates showing the details of its construction, the reader is referred to the Transactions of the Institution of Civil Engineers, vol. i., page 207.

or cement being placed between the stones, which were kept at the proper distances apart by wedges of iron and lead driven in between them. When the whole arch had thus been completed, and the position of the arch-stones carefully examined, a moderately liquid cement composed of equal portions of lime and clean sand was poured into the joints. After which, being allowed twenty days to consolidate, the centers were gradually struck, when the arch subsided with great regularity about $4\frac{2}{5}$ inches, and a load of about 3000 tons of ballast being uniformly distributed over the arch, and allowed to remain for four months, caused a further settlement of $1\frac{1}{5}$ inch, but without producing any irregularity in the form of the arch *.

The elevation (fig. 97) of the bridge constructed by Telford, over the Severn, at Gloucester, has been

Fig. 97.



introduced for the purpose of pointing out a peculiarity in the form of its soffit, first suggested by Perronet, which consists in making the curve of the intrados of the arch flatter at the face than in the

* For a full account of this work, see the Transactions of the Institution of Civil Engineers, vol. i., page 183.

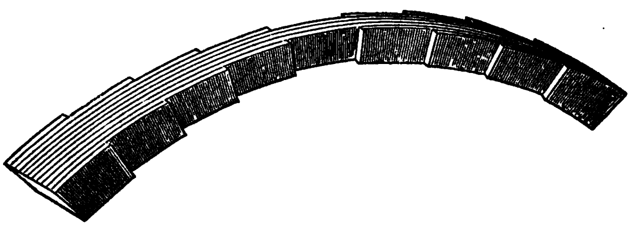
middle of the arch, so as to form a kind of splay on each side, commencing at the haunches and dying away at the crown where the two curves are made to coincide, and at which point alone the soffit of the arch is straight on the transverse section. In the example which we have selected, the form of the arch in the center is an ellipse, as shown by the line 8, fig. 92, while the line of the intrados on each of the external faces of the bridge forms a flat segment of a circle. Perronet himself applied this peculiar mode of forming the soffit in the Neuilly Bridge, over the Seine, already referred to, and the dimensions of which have been given in the table at page 117. The same principle was also adopted in the bridge which we have mentioned above as being constructed over the Dora Riparia, near Turin; but in this case both the curves are segments, only the external one is much flatter than the other. In addition to the pleasing effect of lightness and grace which this method of forming the soffit of an arch affords, it possesses some advantage in saving of material, as well as affording a better form (somewhat resembling that of the contracted vein) for the passage of water, in cases where the river, in time of floods, is liable to rise above the springing of the arch.

In the construction of arches of masonry, some kind of centering is absolutely necessary for the support of the arch-stones, or voussoirs, until the key-stones are inserted. But, in the case of brick arches, Sir Isambart Brunel, some years since, devised a method of constructing them, in which the

use of centering was entirely dispensed with, and in consequence a considerable saving of expense effected. The piers of the bridge having been constructed in the usual manner, up to the springing, he proposed to commence building a portion of the arch right and left, on both sides, taking care that both arches progressed at an equal rate, so that they should always balance each other; in order to increase the cohesion of the structure, he introduced bands of hoop-iron, longitudinally between the courses, in the manner already explained (at page 81 of the First Part), and by these means he was enabled to carry on the two semi-arches, until they met those produced in a similar way from the opposite piers, when, the brickwork being made good between them, the arch was made perfect. He proposed that the arched rib, as it were, thus formed, should not be built more than about 4 feet in width, the true form of the arch being insured by the use of a template, as in building curved walls.

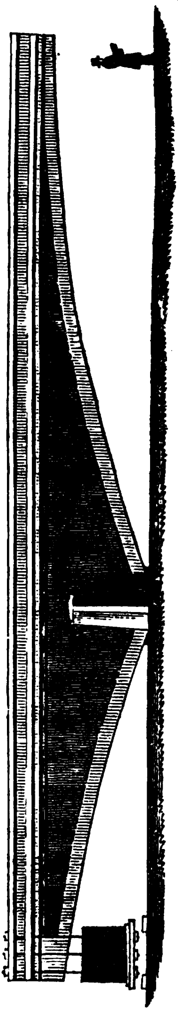
A narrow arch having been completed across, Sir Isambart proposed to extend it to the requisite

Fig. 98.



width by building on each side of it, adding from nine to eighteen inches at a time, and working in steps in the manner shown in fig. 98, so that a great number of bricklayers might simultaneously be employed.

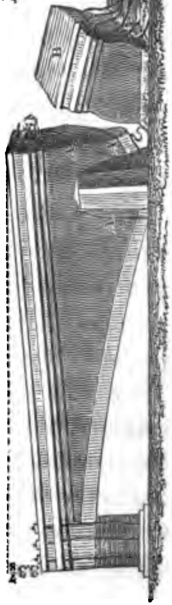
Fig. 99.



It would, probably, by many persons be considered impossible thus to construct a slender arched rib of any extent, which should be capable of sustaining itself with safety, until it had attained a length equal to the semi-span of such an arch as the center one of London Bridge. Sir Isambart, however, set all doubts at rest, and demonstrated its practicability by actually constructing two semi-arches, an elevation of which is shown in fig. 99. They were built of bricks laid with mortar prepared with blue lias lime; several bands of hoop-iron $1\frac{1}{2}$ inch wide and $\frac{1}{12}$th of an inch in thickness, as well as rods of fir about an inch and a half square, and having their edges notched, were inserted longitudinally between the courses, extending throughout the whole length of the structure. The radius of curvature

of the arch was 177 feet, and, although only 4 feet 6 inches in width at the top, it was extended to the length of 40 feet on each side of the center pier. One end was some time after extended another 20 feet, making its total length from the pier 60 feet; and as the other side could not be extended in the same way, in consequence of want of space, a weight amounting to 28½ tons was suspended from it as a counterpoise. The structure having no foundation whatever in the ground, and merely resting upon a Yorkshire landing stone, was disturbed by some deep excavations made within a few feet of its base, which caused the arch to crack upon both sides of the pier, as shown at A, A. Although, however, the fracture extended completely through the substance of the arch, so that light could be seen through it, the structure stood in that state for upwards of three years, during which time it must have been supported by the timber and iron ties already described. The longest arm subsequently fell

Fig. 100.



during the severe frost in January, 1838, in consequence of the expansion of some water (which had found its way into these cracks) while in the act of freezing, the enormous force of which, assisted by the weight of the semi-arch, snapt asunder the ties, and allowed it to fall. Figure 100 exhibits the state of the arch after the accident; the portion which fell separated into three pieces, two of these, B and C, being still united by the hoop-iron bands, which were not broken; the other piece, D, was the portion of 20 feet which had been subsequently added, and which, having been but imperfectly connected with the old work, broke off nearly even, and was not at all injured by the fall. The shorter arm of the arch, being no longer balanced by an equivalent weight, fell over into the inclined position shown in the figure, until it rested upon the top of the weight with which it had been loaded.

Of Cast-Iron Bridges.

The principle which has usually been adopted in the construction of bridges of cast-iron is to support the roadway upon separate ribs, each of which partakes of the properties of an arch, being subjected in like manner entirely to a *compressive* force. They differ, however, essentially from an arch of masonry, in respect of the parts of which these ribs are composed (and which answer to the voussoirs of the arch) being so securely connected together as to prevent the possibility of rotation about their edges, should the line of pressure deviate beyond

the substance of the rib*. In an arch of masonry, the object is so to proportion the depth of the arch in every part, that it may be equilibriated, or, in other words, that the line of pressure may everywhere pass directly through the center of every one of the joints of the voussoirs. In an arched rib of cast-iron, on the contrary, the object is so to form the framing of the ribs and spandrils (which, although in separate parts, should be so connected together as to be one) as to insure the utmost rigidity, and stiffness combined with lightness. It is, then, a matter of small importance, whether the line of resistance passes exactly along the center of the rib, because the whole semi-arch may be looked upon as one huge voussoir, supported at its lower end upon the pier, and at its upper extremity by the equal and similar pressure of the other semi-arch.

We have already† given a rule by which the crushing strain on the rib at the crown of the arch may be determined; it may, however, be desirable to illustrate its practical application; for which purpose we have selected Southwark Bridge. In this case, the weight of half the center arch, with the roadway, is about 1520 tons, and the horizontal distance of the center of gravity of the same from the springing, about 56 feet‡, and the versine or

* See Rudiments of Engineering, Part I., page 49.

† Part I., page 53.

‡ The distance of the center of gravity of the whole mass, from the springing of the arch, is found in the manner explained at page 18, Part I., by multiplying the weight of each separate part by the distance

rise of the arch is 24 feet. Then we have from the rule, as 56 is to 24, so is the horizontal thrust to 1520, which gives 3547 tons for the horizontal thrust at the crown of the arch, or the strain tending to crush the cast-iron ribs. This strain may be supposed, without any sensible practical error, to be equally borne by all the ribs, of which there are eight; and, the sectional area of each being about 214 square inches, we have, for the compressive strain upon every square inch of the ribs, about 4650 lbs., or only $\frac{1}{23}$rd of that which would be required to crush the material*.

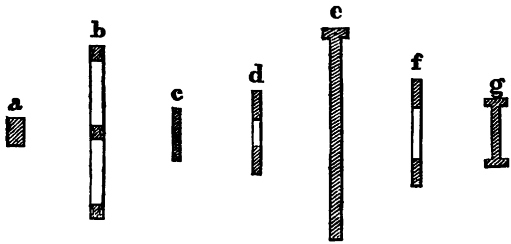
In the following table we have collected the principal dimensions of a few of the more important cast-iron bridges which have been constructed. And in fig. 101 we have shown the sectional forms which have been adopted in each case for the main ribs. We have mentioned at page 69 of the First Part that,

of its center of gravity from the springing, and dividing the sum of the products thus obtained for all the parts of the bridge by the weight of the whole mass.

* It has been supposed by some, that in Southwark, and many other iron bridges, little or no additional strength is derived from the arched form of the ribs, and that the real strain to which they are exposed is similar to that of a girder supported at each end, and loaded with a distributed weight, there being scarcely any horizontal thrust; that such is not, however, the case, is sufficiently evident, by comparing the weight which girders of the same dimensions as the ribs of the bridge, and in the circumstances supposed, would be able to support, with the load which they actually sustain; for, by the rule given at page 68 of the First Part, we find that the weight which would *break* such a girder would be 108 tons, or about 870 tons for the eight ribs of Southwark Bridge, which is less than a fourth of that which they have sustained for many years.

in girders exposed to a transverse strain, their strength may be materially increased by adopting a

Fig. 101.



particular form of cross section; in the case, however, of the ribs of a cast-iron bridge, where they are entirely exposed to a compressive strain, the form of the cross section is immaterial; always, however, supposing that the rib is sufficiently stiff to prevent any tendency to bend laterally, or sideways. The form of those (shown at g in the figure) of the bridge over the Lary appears to be the best adapted for this purpose, the side webs or flanges imparting considerable lateral stiffness to the ribs.

TABLE

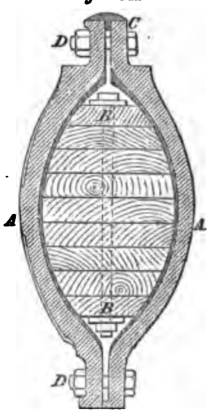
OF THE

DIMENSIONS OF SOME OF THE PRINCIPAL BRIDGES OF CAST-IRON.

Reference to figure 101.	Name and situation of bridge.	No. of arches.	Width of bridge between parapets.	Form of the center arch.	Dimensions of Center Arch.						Manner in which the roadway is supported.	Date of completion.	Engineer.
					Span.	Rise or Versine.	No. of ribs.	Vertical depth of ribs.	Area of each rib.	Thickness of the piers.			
			Ft.		Feet.	Feet.		Feet.	Sq. ins.	Feet.			
a	Colebrook Dale, over the Severn .	1	26	Circular.	100·5	45·0	5	0·75	56·25	—	Cast-iron Plates.	1779	Darby.
b	Sunderland, over the Wear	1	32	Idem.	240·0	30·0	6	5·00	46·50	—	Platform of Timber.	1796	Wilson.
c	Buildwas, over the Severn	1	18	Idem.	130·0	{17·0 34·0	3 2	1·25 1·50	37·50 47·25}	—	Cast-iron Plates.	1796	Telford.
d	Over the Avon, at Bristol	1	31	Idem.	100·0	15·0	6	2·33	32·00	—	Idem.	1806	Jessop.
f	At Bonar, over an arm of the Sea.	1	16	Idem.	150·0	20·0	4	3·00	45·00	—	Idem.	1812	Telford.
g	Vauxhall Bridge, over the Thames	9	36	Idem.	78·0	14·0	10	—	—	10	Idem.	1816	Walker.
e	Southwark Bridge, over the Thames	3	42	Idem.	240·0	24·0	8	6·00	214·00	24	Idem.	1818	Rennie.
f	Tewkesbury Bridge, over the Severn	1	24	Idem.	170·0	17·0	{2 4	3·00 3·00	45·00 36·00}	—	Idem.	1826	Telford.
g	Over the Lary, near Plymouth ..	5	24	{Segment of Ellipse}	100·0	14·5	5	2·00	64·00	10	Idem.	1827	Rendel.
—	Pont du Carrousel, over the Seine	3	35	Idem.	187·0	15·5	5	3·33	165·00	13	Platform of Timber.	1836	Polonceau.

The cross section of the ribs of the Pont du Carrousel is shown in fig. 102 on a larger scale than the others, in order to exhibit more distinctly their peculiar construction. The rib itself is formed of two semi-tubular castings, A, A, which, when put together, form a hollow tube, the interior of which is filled with timber, disposed in several thicknesses, bent to the curve of the ribs, and securely bolted together by the bolt B; the outer form of these timbers was worked a little less than that of the interior tube of the ribs, and the space between them was filled in with asphalte, a capping of which was also put over the joint of the ribs at C, to protect the timber more effectually from the weather. The two iron ribs, A, A, were securely bolted together along their upper and lower edges by bolts, D, D. This method of construction was adopted by the engineer, M. Polonceau, in order to obtain a certain amount of elasticity, combined with the stiffness and solidity belonging to cast-iron. The area of the cast-iron rib itself is 165 square inches, and that of the timber filling about 274 square inches *.

Fig. 102.



* For a detailed description of this bridge, illustrated by engravings, the reader is referred to the Civil Engineer and Architect's Journal, vol. ii., page 79.

Of Suspension Bridges.

Having already explained (at page 60 of the First Part) the principles upon which the construction of suspension bridges depends, and given rules for determining the form of the curve which the chains will assume, and the sectional area which the chains should have in every part, in order to be of uniform strength throughout, it now only remains to offer some remarks upon the practical application of those principles, and then to describe the details of construction of a few of the more important bridges which have been erected upon this principle.

In the case of bridges of masonry and iron, both from the weight of the structures themselves, as well as from the rigid nature of the material, their forms are not liable to be altered, or their equilibrium disturbed, by external influences, such as those arising from the wind, or the transit of heavy loads. With suspension bridges, however, the circumstances are very different, and it has been found that they are materially influenced by these external forces, and, in some cases, have sustained very serious injuries from them. The reason of this is to be found, not only in the extreme lightness of the superstructure of such bridges, in consequence of which but a very slight force is required to put them in motion, but also from their peculiar susceptibility to vibration, or undulatory motion, arising from the center of gravity of the structure being *below* instead

of *above* the point of support, and from the chains being in a state of tension, somewhat similar to the strings of a musical instrument, so that the sudden application of a considerable force to any part of the chain, or the continued and regular impulse of even a slight force, would cause the chains to alter their form, and throw both themselves and the platform into a state of vibration. Thus, suppose the whole line A B D, in fig. 103, to represent the posi-

Fig. 103.

tion of one of the chains of a suspension bridge while in its natural state, and then let us suppose a weight to be suddenly brought upon any point E of the platform, about half-way between the points of suspension and the center of the bridge. Now the effect which this weight will produce will be that of depressing the platform below its ordinary level, and also drawing down the chain by means of the suspension rods, and causing it to assume the form shown by the lower dotted lines; the depression of the chain at F will, however, be attended by an elevation at G, on the opposite side of the center of the bridge, and a corresponding elevation in the platform. The form of the chain will therefore now become as shown by the dotted line A G B F D, and the platform, instead of being level, will have assumed the waved or undulatory form, shown by the dotted

line H E. If, now, this weight be again suddenly removed, the chain and platform will immediately return to their former positions; but in doing so they will have acquired a certain velocity and momentum, sufficient to carry them as much beyond their proper position in the opposite direction, and the chain and platform will assume the form shown by the dotted lines A I B C D and K M, in which the parts previously depressed are now elevated, and *vice versâ;* this position will, however, be only momentary, and they will once more return nearly to the position which they at first assumed when under the influence of the weight. And thus they will continue in a state of vibration until the effects of the disturbing force has been gradually absorbed by the resistance of the chains and platform to motion.

Several suspension bridges have been seriously injured by the strains thus produced by storms of wind, or the transit of heavy loads. Amongst these we may mention the suspension bridge at Broughton, near Manchester, which was broken down on the 12th of April, 1831, in consequence of the vibration occasioned by a company of about 60 soldiers marching over it; they had proceeded about half-way across the bridge, when one of the chains suddenly broke, and the whole of the men were precipitated into the river, although most fortunately without any loss of life. The chain pier at Brighton was also very considerably damaged during a violent storm, which occurred on the 15th of October, 1833, many of the suspending rods being broken, and a con-

siderable portion of the roadway in two of the divisions being carried away. And we have two further instances, in the case of the suspension bridge at Montrose, and that over the Menai Straits, both of which have been very seriously injured by storms of wind; the former on the 11th of October, 1838. on which occasion about one-third of the roadway or platform of the bridge, was entirely carried away; and the latter on the 7th of January, 1839, when more than one-third of the suspending rods were broken, and both the carriage ways rendered impassable, nearly 200 feet of one of them being broken away. During the height of the storm, a wave was observed to traverse the platform in an oblique direction, the height of which was estimated by the bridge-keeper at not less than 16 feet. "The motion was observed to be greatest about half way between the pyramids (or point of suspension) and the center of the bridge. The wave increased in its progress from the pyramid until it attained its maximum altitude near the first quarter, and at the same instant the extreme depression was near the third quarter. The wave then gradually diminished to the center of the bridge, and afterwards increased to the third quarter, when it attained its greatest height at the same time that the first quarter was most depressed. The platform and the main chains were equally subjected to this undulatory motion." *

* Mr. Provis's account of the effects of the wind on the Menai Bridge; Transactions of the Institution of Civil Engineers, vol. iii. p. 359.

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The account here given of what took place on this occasion affords a practical exemplification of what we have shown in fig. 103, the manner in which undulations in the chains and platforms are produced and propagated. These instances are sufficient to show the necessity of adopting some means for preventing, as far as possible, this tendency to undulation in the chains and platform; and they further show the importance of an inquiry into the whole subject of suspension bridges, from which we might learn the laws which regulate these motions in the chains, without a correct knowledge of which all attempts to prevent them are but at best random and uncertain. In all cases, however, it is important to render the platform itself as stiff and rigid as possible, and, further, to connect the chains on each side of the bridge so together as to constitute essentially but one chain, as in those of the Charing Cross Bridge, so that, their weight being greater, they will require a more considerable force to put them into motion than where the chains are separate, as in the Menai Bridge.

We have in the following table given the chief dimensions of some of the principal suspension bridges which have been constructed, either in this country or abroad; and in fig. 104 we have given transverse sections of the chains, showing the arrangement and disposition of the links composing them, which has in each case been adopted.

TABLE

OF THE

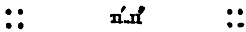
DIMENSIONS OF SOME OF THE PRINCIPAL SUSPENSION BRIDGES.

Nos. of reference to figure 104.	Name and situation of bridge.	Span of the catenary formed by the chains.	Deflexion of the catenary formed by chains.	Deflexion in parts of the span = unity.	Breadth of the platform of the bridge.	Thickness of pier at the level of the platform.	No. of separate chains.	Sectional area of the chains in the center of the bridge.	Size of the separate links composing the chains.	Date of completion.	Engineer.
		Feet.	Feet.		Ft. in.	Feet.		Sq. in.			
1	Union Bridge, over the Tweed	449	30	·067	18 0	17·5	6	38	2 ins. in diameter.	1820	Sir Samuel Brown.
2	Chain Pier at Brighton	255	18	·071	13 0	29	4	25·13	Idem.	1823	Idem.
3	Bridge in the Isle of Bourbon......	220·3	25·48	·116	20 0	12	3	17·4	1·36 ins. in diameter.	1823	Sir I. Brunel.
4	Hammersmith, over the Thames ..	422·25	29·5	·070	30 0	22	8	180	5 ins. × 1 in.	1824	Tierney Clarke.
5	Bridge over the Menai Straits	570	43	·075	28 0	29	16	260	3¼ ins. × 1 in.	1826	Telford.
6	Conway, over an arm of the sea	327	22·33	·068	17 6	—	8	130	Idem.	1826	Idem.
7	Bridge over the Danube at Vienna..	334	21·4	·065	11 10½	21·4	2	15·5	Steel bars, 2·42 ins. × 0·8 in.	1828	Herr von Mitis.
8	Montrose Bridge, over the Este	432	42	·097	12 0	20	4	80	5 ins. × 1 in.	1829	Sir Samuel Brown.
9	Pont des Invalides, over the Seine..	236·5	26·33	·111	25 8	15·5	8	41·6	1·81 ins. in diameter.	1829	M. Navier.
10	Fribourg Bridge, across the valley of the Sarine	870	63	·072	21 3	20	4	Chains composed of 4224 separate wires, each 0·12 in. in diameter.		1834	M. Chaley.
11	Charing Cross Bridge, over the Thames	676·5	50	·074	14 0	30·5	4	296	7 ins. × 1 in.	1845	Isambart K. Brunel.

Fig. 104.

No. 1, Union Bridge.

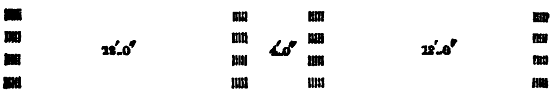
No. 2, Brighton Pier.



No. 3, Isle of Bourbon.

No. 4, Hammersmith Bridge.

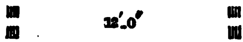
No. 5, Menai Bridge.



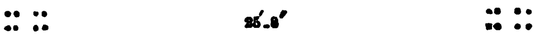
No. 6, Conway Bridge.

No. 7, Bridge of Vienna.

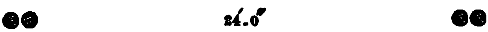
No. 8, Montrose Bridge.



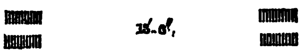
No. 9, Pont des Invalides.



No. 10, Fribourg Bridge.



No. 11, Charing Cross Bridge.



The chains of the Union Bridge, No. 1, the Pier at Brighton, No. 2, the Bridge in the Isle of Bourbon, No. 3, and the Pont des Invalides, No. 9, are formed of rods of round iron; the others, with the exception of the bridge over the Danube, No. 7, and the Fribourg Bridge, No. 10, are formed with flat bars of wrought-iron, grouped together in chains, in the manner shown in the figures. The chains of the bridge over the Danube are of steel, a material adopted by the engineer, H. Mitis, on account of its great strength combined with lightness; it is, however, very questionable whether this supposed advantage is not the reverse, since from the extreme lightness of the chains of this bridge, as compared with the weight of the platform (the latter being

nearly five times as heavy as the former), the bridge is found to vibrate considerably under the influence of heavy loads or high winds, notwithstanding the extreme flatness of the curve formed by its chains, the deflexion being less as compared with the span than that of any of the other bridges mentioned in the table. The chains of the Fribourg Bridge are composed of an assemblage of wrought-iron wires, formed into a bundle or cable, but not twisted; each cable is composed of twelve strands containing each fifty-six wires, and eight strands containing each forty-eight wires, making in the total 1056 wires in each chain or cable. The use of wire as a material for the chains of suspension bridges has been very general on the Continent, and, in many respects, it is well adapted for the purpose. It has, however, been urged against its use, and with some reason, that it is peculiarly liable to corrosion, the fabrication of the chain being favourable to the secretion and retention of moisture within the interstices between the wires, by capillary attraction; and the danger of the interior wires being by these means corroded, without the possibility of its being detected by observation. In the case of the Fribourg Bridge, this evil was guarded against by immersing each wire, three several times, for two hours, in a mixture of boiling linseed oil with a small quantity of litharge and soot; and the same composition was afterwards *payed* over the separate strands, and the finished cables.

With regard to the arrangement of the chains, that

adopted in the Menai and Conway Bridges, Nos. 5 and 6, namely, of having four separate chains, and placing them vertically over each other, is not good, in consequence of the large surface which they thus present to the wind, and, being separate, the slight force required to throw them into motion. This disadvantage was very evident in the case of the Menai Bridge, during the storm to which we have already alluded, when the lateral motion of the chains was so considerable, that, although suspended at a distance of 12 feet apart (as shown in the section), "they had, after the breaking of the transverse ties and tubes, been thrown so violently against each other as to cause deep indentations in the iron and to break off the heads of the bolts, the shanks of which were 3 inches in diameter."*

In arranging the proportions to be given to the several parts of a suspension bridge, the spans and deflexions of the contiguous openings must be so adjusted, that the horizontal strains produced by the chains on each side of the pier shall be equal, and consequently balance each other; for, otherwise, unless the saddle to which the chains are connected were fixed, it would be drawn off the pier in the direction of the greater strain, and, if it were fixed, the stability of the pier would be endangered, from the tendency of the greater strain to pull it over. It may easily be ascertained whether this equality in the horizontal strains

* Mr. Provis's account (before quoted), p. 364.

exists or not, in the following manner: having assumed certain proportions for the two openings, calculate, by means of the rule already given*, the strain upon the chains of each opening (taking as the point D that in which the chains meet the pier); the strains thus obtained will be those acting in the direction of the chains, and, in order to ascertain the equivalent horizontal strains, we must, by means of the first rule at page 63 of the First Part, find two points in each of the chains near the pier, from which we shall ascertain their directions, and we may then easily find the amount of the horizontal strains, by resolving each of the strains acting in the direction of the chains into two others, one acting vertically, and the other horizontally, in the same manner as has been already explained at the commencement of the third Chapter. Should it thus be found, that the horizontal strain produced by the chains on one side of the pier would be greater than that produced upon the other, their relative poportions must be varied, until they are made to balance each other.

* Rudiments of Civil Engineering, Part I., page 64.

G. Woodfall and Son, Printers, Angel Court, Skinner Street, London.

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